Alaska Monitoring and Assessment Program 2015 National Petroleum Reserve Alaska Estuary Survey

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List of Acronyms

DEC	Alaska Department of Environmental Conservation
AKMAP	Alaska Monitoring and Assessment Program
BOEM	Bureau of Ocean Energy Management
EPA	Environmental Protection Agency
ERL	effects range - low
ERM	effects range - median
NARS	National Aquatic Resource Surveys
NCCA	National Coastal Condition Assessment
NPR-A	National Petroleum Reserve-Alaska
NOAA	National Oceanic and Atmospheric Administration
NS&T	National Status and Trends
OCS	outer continental shelf
PAH	polycyclic aromatic hydrocarbon
PMEL	Pacific Marine Environmental Laboratory
TPAH	total polycyclic aromatic hydrocarbon
UAF	University of Alaska Fairbanks

Abstract

In August 2015, the Alaska Monitoring and Assessment Program (AKMAP) surveyed the National Petroleum Reserve - Alaska (NPR-A) estuaries as part of the Environmental Protect Agency's (EPA) National Coastal Condition Assessment (NCCA). The NPR-A estuary survey was a joint effort by the Alaska Department of Environmental Conservation (DEC), the University of Alaska Fairbanks (UAF), the Alaska Coastal Marine Institute (CMI), the National Oceanic and Atmospheric Administration (NOAA), and the Bureau of Ocean Energy Management (BOEM).

The NPR-A estuary survey was based on the NCCA survey design, condition indicators, and analysis protocols. The NCCA uses a probabilistic survey method that estimates the spatial extent of ecological condition based on stressors and indicators. The NCCA uniform sampling methods and analytical procedures allow for comparison of conditions nation-wide. Stressors, such as chemical contaminants and water quality parameters, and indicators, such as macroinvertebrate biodiversity, are used at each station to relate biological response, contaminant exposure, and habitat condition. This integrated approach provides better evaluation and assessment of ecosystem status than traditional monitoring, which typically emphasizes single media and a stand-alone approach. The goals for the survey were to assess the condition of estuarine aquatic resources, as delineated by established water quality criteria, and to provide baseline data for future trend assessment.

Due to weather and local conditions, 83% of planned sites were sampled for water quality parameters. Sediment chemical and macroinvertebrate sampling success were 80% and 53%, respectively, largely because of problems sampling compact sediments. Overall, estuary coverage for the original design population represented 2,971 $km^{2,}$ and the final sampled population represented 1,739 km^2. Missed sampling stations limit the ability to generalize for the region, so these results apply only to the estuaries sampled.

The 2015 NPR-A estuary survey only provides the condition or a "snapshot" of the environmental condition for late summer. Overall, the environmental condition of NPR-A estuary area sampled population for the monitoring period is good. This rating is based on water quality and sediment quality indices used to assess regional environmental condition. Relative rankings of good, fair, or poor of component indicators are based on comparisons to cut points developed from DEC water quality standards and/or other numeric criteria.

Generally, both macroinvertebrates and demersal fish living in or on the sediments are considered good indicators of physical and chemical changes to their habitat. There is no DEC benthic macroinvertebrate criterion for Alaska's coastal waters so benthic macroinvertebrate data was not used in ranking. The baseline macroinvertebrate results showed species composition differed between estuaries, likely due to habitat differences. Although informative, the results of fish tissue contaminant analysis could not be used in estimating overall area environmental

condition because the fish sample size was too small. Seven fish were analyzed for hydrocarbons and organochlorines and ten fish for trace metals. These fish are an important component in the estuary food web for marine mammals, such as seals. Evaluated against EPA benchmark criteria , tissue contaminant levels were very low except for the mercury (Hg) concentration in one fish from Elson Lagoon. There were some site and species-specific differences but no obvious contaminant patterns.

Macroinvertebrates and fish appear to be seasonal residents of the NPR-A estuaries, raising questions about the usefulness of these organisms for environmental monitoring within the shallow landfast estuaries. With the exception of Peard Bay, which has a deep water basin (~ 7 meters), bottom and landfast ice conditions add stress and may result in species dying-off or advecting out of the estuaries with recolonization in the spring. With limited estuary residence time, it becomes difficult to correlate tissue contaminates or macroinvertebrate community changes to estuary conditions. Monitoring sediments and water for physical and chemical changes may provide a better approach to assessing anthropogenic impacts.

Introduction

Numerous marine environmental studies have been conducted in or near to the National Petroleum Reserve-Alaska (NPR-A) estuaries, with a majority evaluating potential impacts from oil and gas development (Wiseman, 1979; Carey et al., 1984; Feder et al., 1989; Naidu et al., 2006; Naidu et al., 2012; Venkatesan et al., 2013; Trefry et al., 2013, 2014). These studies provide important information to resource managers but were typically geographically limited and focused on specific sets of resources and variables. Effective resource management at local, regional, and national scales is limited when informed only by individual targeted studies because such studies cannot be used to assess the condition of aquatic resources over large areas, such as coastal estuaries across the United States (Summer et al., 1995; Urquhart et al., 1998; Bernstein and Weisberg, 2003).

In the 1990s, the Environmental Protection Agency (EPA) Office of Research and Development and numerous partners developed and tested a probabilistic sampling survey design that used multiple indicators for an integrated approach. The design supports the assessment of the condition of an entire aquatic resource across a geographic area (Olsen et al., 1999). This environmental sampling methodology evolved into the current EPA National Aquatic Resource Surveys (NARS), which are used to assess the condition and trends in quality of the nation's coastal waters, lakes and reservoirs, rivers and streams, and wetlands (U.S. EPA, 2017). The National Coastal Condition Assessment (NCCA) is one of four national survey programs under the NARS. The NCCA surveys, which use the aforementioned probabilistic design, are very efficient as they require relatively few sampling locations to make valid scientific statements about the condition of the overall population of large areas (e.g., all estuaries within NPR-A) (Paul et al., 2001, 2011; Trowbridge and Jones, 2009).

Recognizing a need to assess the condition of Alaska's aquatic resources, the Alaska Department of Environmental Conservation (DEC) incorporated NARS NCCA methods into its ongoing Alaska Monitoring and Assessment Program (AKMAP). The AKMAP surveys support Clean Water Act 305(b) reporting and provide data to inform DEC wastewater permitting and monitoring, risk assessments, and assessments of baseline ecological condition, temporal trends, and cumulative impacts. As of 2018, AKMAP has conducted coastal marine surveys in Southeast, Southcentral, Aleutians, Chukchi Sea, Simpson Lagoon, and NPR-A estuaries. The Cook Inlet Regional Advisory Council (2018) applied the NARS survey design to Cook Inlet assessments in 2008 and 2009. The next AKMAP NARS project is scheduled in Southeast Alaska in 2020.

In 2009, DEC decided to focus AKMAP surveys on the Chukchi Sea coastal area and NPR-A over five years (DEC, 2018). This decision was influenced by the 2008 Bureau of Ocean Energy Management (BOEM) offshore lease sale in the Chukchi Sea and development plans for the NPR-A. These actions added urgency for establishing a pre-development baseline survey of water quality and ecological condition in the region. The Chukchi Sea survey (2010–2012) covered the 25- to 50-mile exclusion corridor between the nearshore (~10–50 m depth) and the BOEM oil/gas Lease Sale #193. The Simpson Lagoon survey (2014) assessed current and historical sediment trace metal concentrations. The NPR-A estuary surveys (2011, 2013–2015) took a watershed-to-estuary assessment approach, focusing on wetlands, lakes, rivers, and estuaries. AKMAP stations sampled between 2010 and 2015 are shown in Figure 1.

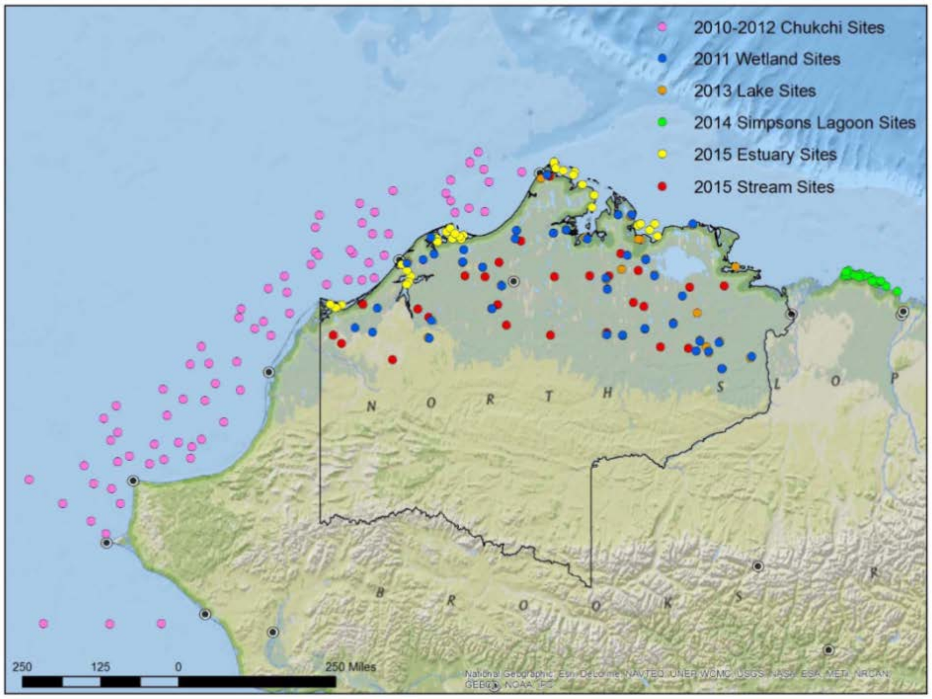

Figure 1. AKMAP Arctic aquatic resource survey stations 2010–2015.

Offshore oil and gas exploration in the Chukchi Sea was suspended in 2015 with the oil companies shutting down their exploration efforts; however, development efforts in NPR-A continued to move forward. In February 2013, the Bureau of Land Management designated 900 tracts (approximately 10.3 million acres) for oil and gas leasing (United States Department of the Interior, 2013, 2017), and two NPR-A estuaries, Smith Bay and Harrison Bay, contain State of Alaska lease tracts available for oil and gas development. Caelus Energy Alaska drilled two exploration wells in Smith Bay (~ 241.4 km west of Prudhoe Bay) in 2015 (Lidji, 2017).

This report provides results of the 2015 AKMAP NPR-A estuary survey, a joint effort by the Alaska Department of Environmental Conservation (DEC), the University of Alaska Fairbanks (UAF) Institute of Marine Science, the Alaska Coastal Marine Institute (CMI), the National Oceanic and Atmospheric Administration (NOAA), and the Bureau of Ocean Energy Management (BOEM). The NPR-A estuary survey utilized the established NCCA probabilistic sampling design to estimate the spatial extent of ecological conditions based on stressors and indicators (U.S. EPA, 2016).

Methods

Study Area

Surveys were completed in five estuaries: Kasegaluk Lagoon, Wainwright Inlet, Peard Bay, Elson Lagoon/Dease Inlet, and Smith Bay (Figure 2). Sampling was planned for Harrison Bay but did not occur due to weather and other project limitations.

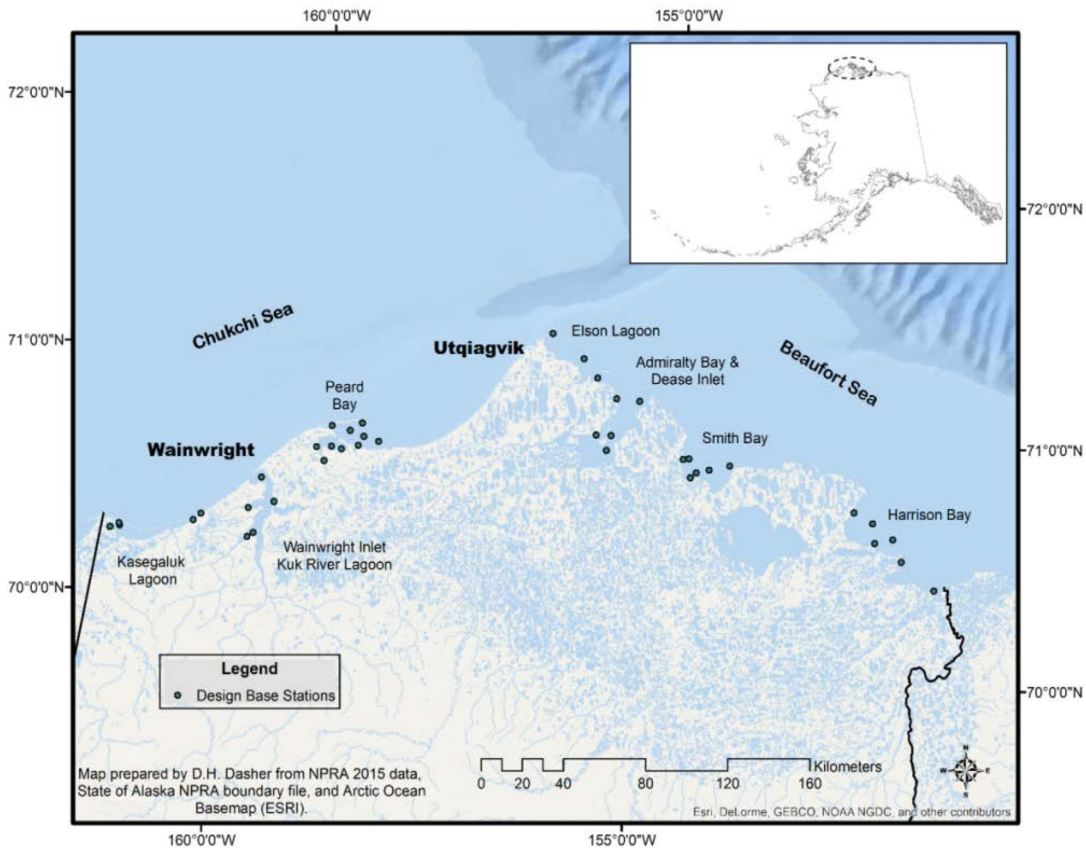

Figure 2. NPR-A estuary survey stations.

Except for Peard Bay, which reaches depths of 7 meters, all of the estuaries sampled are shallow (generally <4 meters), and their embayments are covered with bottom and landfast ice in winter (Outer Continental Shelf Environmental Assessment Program [OCSEAP], 1985; Reimnitz et al., 1987). The median depth for the NPR-A estuary stations surveyed was 2.4 meters. For the sampled population, 28% of the area was ≤ 2 meters deep, 65% of the area was 2–5 meters deep, and 3% was ≤ 7 meters deep. Freshwater input to the estuaries is from rain, snowmelt, rivers, and groundwater. The Utukok River, which flows into the Kasegaluk Lagoon, is the only watershed in this study that reaches as far south as the foothills of the Brooks Range. The river enters the lagoon below Icy Cape and effectively bisects the lagoon into north and south embayments, each with multiple inlets through the barrier islands that form the lagoon.

Wainwright Inlet is fed by the Kuk River and the smaller Kungok River to the east. There are exposed deposits of coal along the shoreline. Peard Bay lies behind Pt. Franklin and the Seahorse Barrier Islands. It has a very limited watershed via Kugrua Bay, which joins Peard Bay on the southwest side. Peard Bay is frequented by seals and the occasional gray whale (OCSEAP, 1985).

The Chukchi coastal water mass is dominated by northward-flowing currents that originate in the Bering Strait and mix with the NPR-A estuarine systems by tidal exchange. Frequent storm winds may overwhelm tidal exchange in both flood and ebb directions. The proximity of Barrow Canyon is of particular importance; here, the flow of water from the Chukchi enters the Arctic Ocean and strong flow reversals and upwelling from the canyon onto shelf waters are common (Pisareva et al., 2017).

On the Beaufort Sea side, Elson Lagoon lies immediately east of Pt. Barrow and is contiguous with Dease Inlet to the east. The Plover Islands, which rim the seaward side of the lagoons, allow multiple passes to the Beaufort Sea. The shallow embayment of Admiralty Bay, south of Dease Inlet, is bounded on three sides by land. Collectively, these water bodies are fed by the Meade River (draining the coastal plain) and various smaller rivers that empty into Dease Inlet and Elson Lagoon. Smith Bay lies to the east and receives freshwater input from the Ikpikpuk River, which is also a coastal plain watershed. Smith Bay is shallow, open to the Beaufort Sea with no barrier island protection, and has an expanding delta at the river mouth. Harrison Bay, east of Cape Halkett, is 80 km wide and is a shallow bay without barrier island protection. Harrison Bay is fed by the Colville River, the largest river on the Alaskan North Slope, which drains both the coastal plain and Brooks Range.

The dominant coastal currents in the western Beaufort Sea flow from east to west but are reversed by storms from the northwest. The very large Canadian Mackenzie River along with the Colville River and numerous smaller rivers along the Beaufort coast supply enough fresh water to the system to maintain near-estuarine conditions along the coast (Dunton et al., 2012). Wind-driven water exchange frequently overwhelms tidal flushing during ice-free periods. The vast majority of fresh water enters the systems during spring floods when the snow melts in June (Rember and Trefry, 2004). Large volumes of sediment and terrestrial organic matter are delivered to the estuaries during these periods.

During freeze-up in late September/early October, bottom-fast ice develops from the shoreline to around the 2-meter isobath, with discontinuous bottom-fast and anchor ice occurring out to the 5-meter isobath (Reimnitz et al., 1987). Landfast ice then covers the deeper (> 5 meters) parts of the estuaries. The ice cover lasts for 9–10 months of the year. During winter, there is no freshwater input from the frozen tundra, and brine pockets of very high salinity form under the ice. Tidal exchanges in the Chukchi and Beaufort Seas are small, varying by a foot or less.

NPR-A Estuary Survey Design

The NPR-A estuary survey followed the 2010 NCCA design (U.S. EPA, 2015). The survey target population was mapped using NOAA's Environmental Sensitivity Index coastline for the North Slope and modifying some shorelines to reflect erosion based on 2010 satellite imagery. Estuaries were defined as any tidally influenced water with less than 50% of its perimeter adjacent to the ocean. A Generalized Random-Tessellation Stratified survey design for an area resource was used to locate the stations. Forty stations were selected for sampling with additional oversample points identified for use if sampling sites accessed in the field did not match the target population definition. Based on discussions with a local expert (boat captain), and in light of significant shoreline erosion in the region, existing bathymetry data was considered too inaccurate for use in sampling design or vessel operations, compromising the ability to include depth considerations in the sample design. Instead, the sampling frame was divided into two non-overlapping strata: the Chukchi Sea and Beaufort Sea estuaries. This stratification was based on expectations that water quality physical characteristics (e.g., temperature, salinity) were not similar between strata. Sampling 20 stations from each strata would allow testing for statistical differences between them. Appendix A provides a glossary of survey-related terms, and Appendix B provides the design metadata, station locations, and maps.

NPR-A Estuary Survey Indicators

The NPR-A estuary survey measured four categories of indicators as specified by the NCCA design (U.S. EPA, 2015; Table 1).

Table 1. NCCA indicators used in the NPR-A estuary survey.

Biological	Chemical/Toxicity	Physical	Recreational/Human Health
Chlorophyll a	Salinity	Water clarity	Fish tissue contaminants
Benthic macroinvertebrates	Nitrogen		
Fish tissue contaminants	Phosphorus		
	Dissolved oxygen		
	Sediment toxicity		
	Sediment contaminants		

Indicators are characteristics of the aquatic resource that are sampled to provide quantitative or semi-quantitative data on the condition of the aquatic resource. Biological indicators, such as benthic organisms, or physical characteristics, such as salinity, are used to evaluate the condition of the aquatic resource when compared to an established environmental value. Biodiversity of marine sediment macroinvertebrates is a condition indicator for the environmental quality of the waters. Physiochemical water quality characteristics affect the ability of species to persist in a given habitat. Indicating stressors, such as low dissolved oxygen or petroleum hydrocarbon contamination, may result in measurable changes in condition indicators, such as benthic or fish community structure. Sediment hydrocarbons and trace metals were also sampled to address concerns of potential toxicity from oil and gas activities (see analyte lists in Appendix C).

Project Organization

The 2015 NPR-A estuary survey was a joint effort. University of Alaska Fairbanks Institute of Marine Science researchers participated in the planning the survey design and field work and provided field team members, laboratory analysis, data analysis, QA/QC, data management, and report writing. The Alaska Department of Environmental Conservation (DEC) assisted with survey planning and provided field team members, field equipment and supplies, data QA/QC, data entry in the Alaska Water Quality Database, and review of draft reports. The NOAA National Center for Coastal Ocean Service made the project possible by providing vessel time on the NOAA *Ron Brown* and access to the *Peggy D* boat for estuary operations. The NOAA Pacific Marine Environmental Laboratory (PMEL) analyzed water for nutrients. In addition, NOAA provided personnel, including a primary lead scientist and field personnel, coordinated analytical work, and assisted with data QA/QC, data analysis, and report writing and review.

Field Operations

Field sampling operations were designed to align with 2010 NCCA protocols (Table 2). The NOAA vessel *RV Ron Brown* served as base of operations, and a smaller launch, the *Peggy D*, was used for estuary sampling. Typically, the *Peggy D* was launched in the morning and returned each evening to process and store samples. Sampling was planned to start in upper Kasegaluk Lagoon and proceed to Wainwright Inlet, Peard Bay, Elson Lagoon/Dease Inlet, Smith Bay, and Harrison Bay before debarking at Utqiagvik.

Water column data was collected with a conductivity, temperature, and depth (CTD) instrument and direct sampling with Niskin bottles. A Ponar sampler was used to collect surficial sediments for macroinvertebrate sampling and sediment chemistry. A small beam trawl was used to collect fish for tissue contaminants. The scheduled sequence of sampling events for each station was

1. Confirm station location was within ± 0.02 nm (37m) against *Peggy D* GPS readings,
2. Check salinity to confirm ≥ 0.5 measurements practical salinity units (PSU),
3. Take depth measurements,
4. Deploy underwater camera at the site location to assess benthic habitat visually,
5. Take Secchi disk transparency measurements,
6. Complete CTD cast/profile
7. Complete additional water measurements (pH, photosynthetically active radiation, etc.),
8. Take water samples for nutrients, chlorophyll *a*, and total suspended solids (TSS),
9. Sample sediment with a Ponar sampler for macroinvertebrates (screen through stacked 1 mm and 0.5-mm sieves), and
10. Complete 1-meter beam trawls to collect epifauna and fish for contaminant assessment.

Laboratories Utilized

Sample analyses were split between the NOAA, TDI-Brooks (subcontractor), DEC, and UAF.

- TDI-Brooks International, Inc.: Sediment trace metals; polycyclic aromatic hydrocarbons (PAHs); aliphatic hydrocarbons; saturated biomarkers; total organic carbon; total carbon; and fish tissue analysis for organochlorine contaminants, PAHs, and trace elements.
- UAF: Institute for Marine Science (IMS)–macroinvertebrate sorting and identifications, chlorophyll *a*, and grain size analysis. Alaska Stable Isotope Facility–sediment carbon and nitrogen stable isotope analysis.
- NOAA (PMEL): Seawater total and dissolved nutrient analysis.
- DEC: Collection and analysis of CTD measurements.

Macroinvertebrate Processing

One concern in evaluating changes in benthic macroinvertebrate populations is the sieve size used to screen the animals out of the sediments. The NCCA program used a 1.0-mm sieve screen size for west coast and Alaska surveys through 2010 and then reduced the sieve mesh size to 0.5 mm. The NOAA National Status and Trends bioeffects studies and the EPA Environmental Monitoring and Assessment Program (EMAP) studies on the east and Gulf coasts also use a 0.5-mm sieve. Therefore, it was important to evaluate the relevance of sieve mesh size used in this survey because changing size impacts future sampling design and could make new data incompatible with historical 1.0-mm mesh data. For this survey, benthic samples were sieved through nested 1.0-mm and 0.5-mm sieves to compare techniques. The 1.0-mm and 0.5-mm collections were kept separate for taxonomic work, and the results were combined to assess differences between sieve size collections.

Quality Assurance/Quality Control

The NPR-A estuary survey generally followed the 2015 NCCA Quality Assurance Protocols (U.S. EPA, 2015). Laboratory methods were performed in general accordance with the NCCA standards but were adapted to methodologies specific to individual organizations. Adapted methodologies included using PMEL nutrient methods, using NOAA quality assurance contract requirements in TDI-Brooks work (TDI-Brooks, 2016a, 2016b), using Alaska Stable Isotope Facility methods for carbon and stable isotope analysis, and using IMS procedures for macroinvertebrate taxonomy, chlorophyll *a*, and total suspended solids.

Statistical Analysis

Data analysis procedures for estimates of overall and subpopulation (Beaufort and Chukchi) condition were directly linked with the NARS NCCA survey design methodology. Appendix D provides cumulative distribution function (CDF) plots for water column dissolved nutrients and chlorophyll *a*, *and* sediment trace metals, hydrocarbons, grain size, and total organic carbon (TOC). The EPA survey package (*spsurvey*) within the R statistical program *environment* was used in the survey design to adjust design parameters, such as site weights, and to develop final population estimates for the data collected. The *cont.cdftest* in *spsurvey* was used to test statistical differences between the Chukchi and Beaufort estuaries. Summary and exploratory statistics were used to provide a deeper understanding of the dataset. Sediment trace metals and macroinvertebrate data were assessed using linear regression, principal components analysis, nonmetric multidimensional scaling, and nonparametric MANOVA.

Data Management

The NPR-A estuary survey followed the NCCA Quality Assurance Plan protocols for information management, standards, transfer protocols, data quality and results validation, metadata, security, and long-term data accessibility and archiving. Data is available directly from the Alaska DEC Division of Water, Alaska Monitoring and Assessment Program. Archived data can be requested from EPA (STORET database), NOAA (National Status and Trends database), and DEC (Ambient Water Quality Monitoring System database).

Results and Discussion: Sampling and Analyses

Sampling activities took place 14–24 August 2015 (Table 2). Weather and safety concerns due to the presence of sea ice prevented sampling the seven stations in Harrison Bay resulting in only 33 of 40 planned stations (not including duplicates) being sampled. Estuary coverage for the original design population represented 2,971 square kilometers and the sampled population represented 1,739 square kilometers. Twenty stations were sampled in the Chukchi Sea estuary stratum and 13 in the Beaufort Sea stratum (Figure 3). All 33 stations had water column samples collected, 32 stations had sediment chemistry and physical parameter collections, and 21 had macroinvertebrates collected. Duplicate samples were taken at stations 005 and 106. No sediment samples were collected at station 101 due to loss of the Ponar grab sampler. Limited trawls were conducted due to weather, boat time constraints, and lack of biomass.

Benthic sampling was confounded due to compacted sediments that made Ponar grab penetration difficult; it did not always reach the target depth of three to five centimeters. Adding weight to the Ponar grab helped penetration, but the *Peggy D* winch had difficulty handling the additional weight when pulling the Ponar grab out of the compacted sediment layer. Several samples per station had to be composited to collect enough material for sediment chemistry samples. Due to the sampling difficulties, biological collections were only possible at a few stations

Due to the exclusion of Harrison Bay, the AKMAP survey represents a smaller area than planned but still meets the minimum survey objective of 20 stations to provide spatial estimates of condition across NPR-A estuaries. Overall, this survey sampled 83% of planned sampling sites for water quality parameters but, due to sediment conditions, sediment chemical and macroinvertebrate sampling success were 80% and 53%, respectively. Some stations in the estuaries were excluded from the final survey analysis because the depth was too shallow for access and sampling by the *Peggy D* (<1–1.5 meters). Statistical testing for differences between strata or subpopulations (i.e., Chukchi versus Beaufort estuaries) could not be completed as it required a minimum of 20 stations within each stratum, which was not achieved.

Table 2. NPR-A estuary sampling sites and NCCA-aligned sampling activities.

													NCCA Parameters	
Site ID	**Sample Date**	**Estuary**	Depth in feet	Depth in meters	Secchi Depth (m)	CTD profile	Nutrient Sample	TSS Sample	Chlorophyll	Underwater	Benthic	Sediment	Trawl Conducted	Fish Collected
AK-NCCA15-024	8/14/2015	Kasegaluk Lagoon	10	3	X	X	X	X	X	X		X		
AK-NCCA15-044	8/14/2015	Kasegaluk Lagoon	8	2.4	X	X	X	X	X	X		X		
AK-NCCA15-028	8/14/2015	Kasegaluk Lagoon	10.5	3.2	X	X	X	X	X	X		X		
AK-NCCA15-016	8/14/2015	Kasegaluk Lagoon	7	2.1	X	X	X	X	X	X		X	X	
AK-NCCA15-011	8/15/2015	Wainwright Inlet	10.5	3.2	X	X	X	X	X		X	X		
AK-NCCA15-039	8/15/2015	Wainwright Inlet	10	3	X	X	X	X	X		X	X		
AK-NCCA15-047	8/15/2015	Wainwright Inlet	9	2.7	X	X	X	X	X			X		
AK-NCCA15-051	8/15/2015	Wainwright Inlet	11.3	3.4	X	X	X	X	X		X	X	X	
AK-NCCA15-015	8/15/2015	Wainwright Inlet	13.3	4.1	X	X	X	X	X			X		
AK-NCCA15-013	8/18/2015	Peard Bay	15.7	4.8	X	X	X	X	X	X	X	X		
AK-NCCA15-037	8/18/2015	Peard Bay	11.8	3.6	X	X	X	X	X	X		X		
AK-NCCA15-005	8/18/2015	Peard Bay	8.2	2.5	X	X	X	X	X	X	X	X		
AK-NCCA15- 105**Dup**	8/18/2015	Peard Bay	8.2	2.5			X	X	X		X	X		
AK-NCCA15-025	8/18/2015	Peard Bay	19.7	6	X	X	X	X	X	X		X		
AK-NCCA15-033	8/19/2015	Peard Bay	11.5	3.5	X	X	X	X	X	X	X	X		
AK-NCCA15-009	8/19/2015	Peard Bay	11	3.4	X	X	X	X	X	X	X	X		
AK-NCCA15-049	8/19/2015	Peard Bay	13.5	4.1	X	X	X	X	X	X	X	X		
AK-NCCA15-018	8/19/2015	Peard Bay	22.5	6.9	X	X	X	X	X			X	X	X
AK-NCCA15-050	8/19/2015	Peard Bay	22	6.7	X	X	X	X	X	X	X	X		
AK-NCCA15-010	8/19/2015	Peard Bay	22	6.7	X	X	X	X	X	X	X	X		
AK-NCCA15-065	8/20/2015	Elson Lagoon	9.2	2.8	X	X	X	X	X	X	X	X		
AK-NCCA15-114	8/20/2015	Elson Lagoon	10.2	3.1	X	X	X	X	X	X	X	X		
AK-NCCA15-095	8/20/2015	Elson Lagoon	12	3.7	X	X	X	X	X	X	X	X		
AK-NCCA15-107	8/20/2015	Elson Lagoon	7	2.1	X	X	X	X	X	X	X	X		
AK-NCCA15-079	8/20/2015	Elson Lagoon	7.5	2.3	X	X	X	X	X	X	X	X		
AK-NCCA15-067	8/20/2015	Elson Lagoon	10.5	3.2	X	X	X	X	X	X	X	X		
AK-NCCA15-069	8/21/2015	Elson Lagoon	8	2.4	X	X	X	X	X	X		X		
AK-NCCA15-082	8/21/2015	Elson Lagoon	6	1.8	X	X	X	X	X	X	X	X		
AK-NCCA15-066	8/23/2015	Smith Bay	8	2.4	X	X	X	X	X	X	X	X		
AK-NCCA15-106	8/23/2015	Smith Bay	8	2.4	X	X	X	X	X	X	X	X		
AK-NCCA15-106**Dup**	8/23/2015	Smith Bay	8	2.4		X	X	X	X		X	X		
AK-NCCA15-113	8/23/2015	Smith Bay	7.5	2.3	X	X	X	X	X	X		X		
AK-NCCA15-101	8/24/2015	Smith Bay	13	4	X	X	X	X	X	X				
AK-NCCA15-073	8/24/2015	Smith Bay	6	1.8	X	X	X	X	X	X		X		
AK-NCCA15-120	8/24/2015	Smith Bay	8	2.4	X	X	X	X	X	X		X	X	X

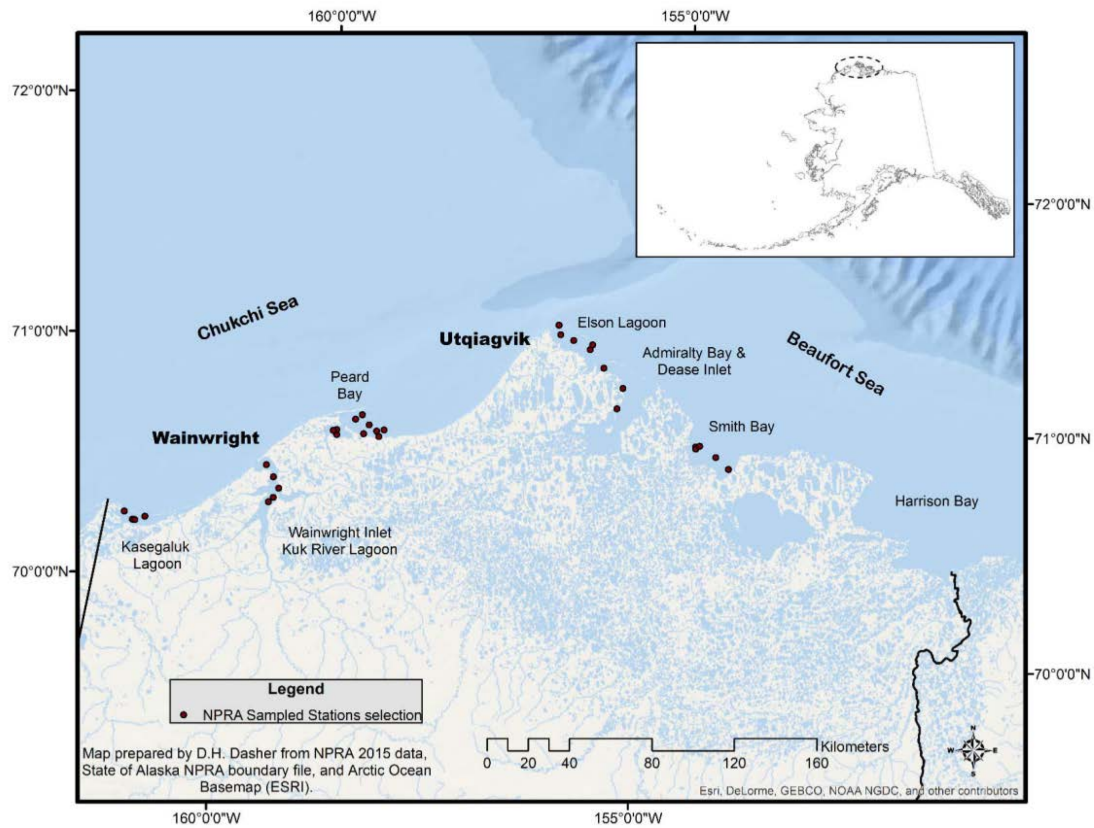

Figure 3. Stations sampled in the 2015 NPR-A estuary survey.

NPR-A Estuary Habitat Parameters

Habitat parameters that influence species and contaminant distribution were measured at each sampling site. These included depth, salinity, temperature, dissolved oxygen (DO), sediment grain size, and organic carbon content. Within the estuaries, sediment type was almost exclusively mud (silt+clay), with silt making up the major fraction of the mud in many cases. A few locations very close to shorelines were composed of coarser sand or a mix of silt and sand. There were multiple shoals present in all locations. The watersheds are flat, low energy systems that, outside of short-lived spring flooding, do not deliver loads with variable sediment types.

Due to tidal and wind mixing, the shallowness of the estuaries, and the silty nature of the sediment, water clarity was poor as measured by Secchi disk, averaging less than one meter over all sites. In many cases, Beaufort Sea estuary stations had less clarity than the Chukchi Sea stations, mirroring the TSS distribution. Attempted underwater camera footage was degraded due to windy conditions, boat movement, and suspended sediment in the water column.

Based on the salinity and temperature profiles, the water column was well mixed in all places. Except for sites near freshwater inputs, most sites had relatively high salinities, reflecting the tidal influence of seawater into the estuaries and the low input of freshwater in late summer. Temperatures were cooler on average in the Beaufort estuaries than in the Chukchi estuaries. Bottom DO measurements indicated well-oxygenated conditions with no observed hypoxic (DO < 2 mg/l) conditions.

Except for Peard Bay, all of the estuaries reflected a strong influence of terrestrial plant input with very low δ ‰ values for stable carbon and nitrogen isotopes (Figure 4). Peard Bay has a very limited watershed, is deeper than the other estuaries, and is strongly influenced by tidal exchange with marine waters.

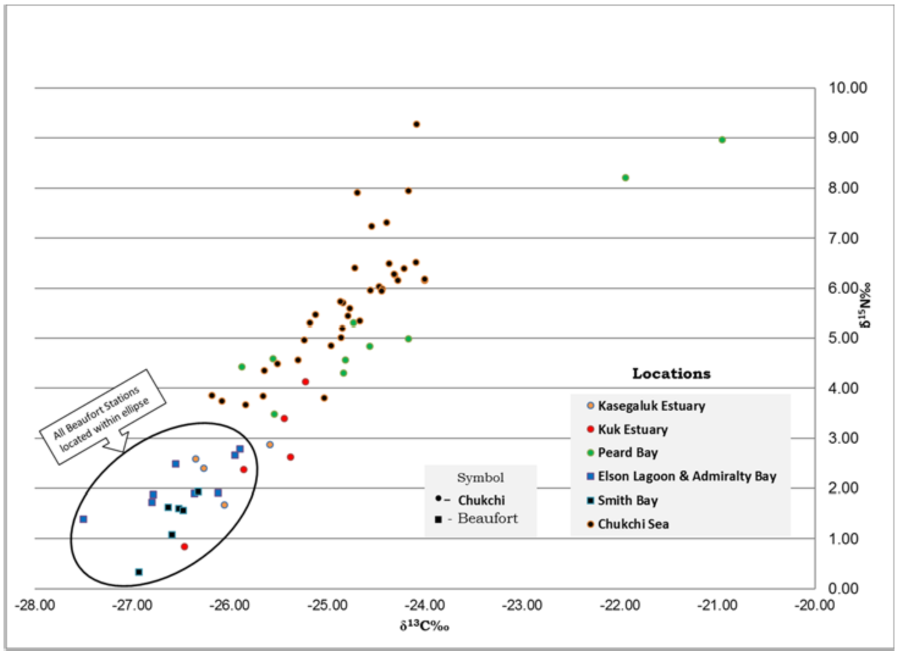

Figure 4. Carbon and nitrogen isotope plot by survey station.

Trace Metals

There were no obvious patterns in the distributions of the major metals and trace metals. Sediments dominated by sand contained lower levels of all trace elements than fine-grained sediment, which has a higher surface to volume ratio than sand. The major constituents of sediments are Al and Fe, or Si, depending on the watershed geology and depositional environment (e.g., sand or mud). Normally, there is a relationship between trace elements and the major elements, either negative or positive. Ordinary least squares (OLS) regression plots of Al versus elements can be used to identify locations where outliers indicate anthropogenic pollution inputs or naturally occurring localities with unusual geologic inputs. The positive relationship between dry weight (dw) concentrations of aluminum and iron shown in Figure 5 is typical.

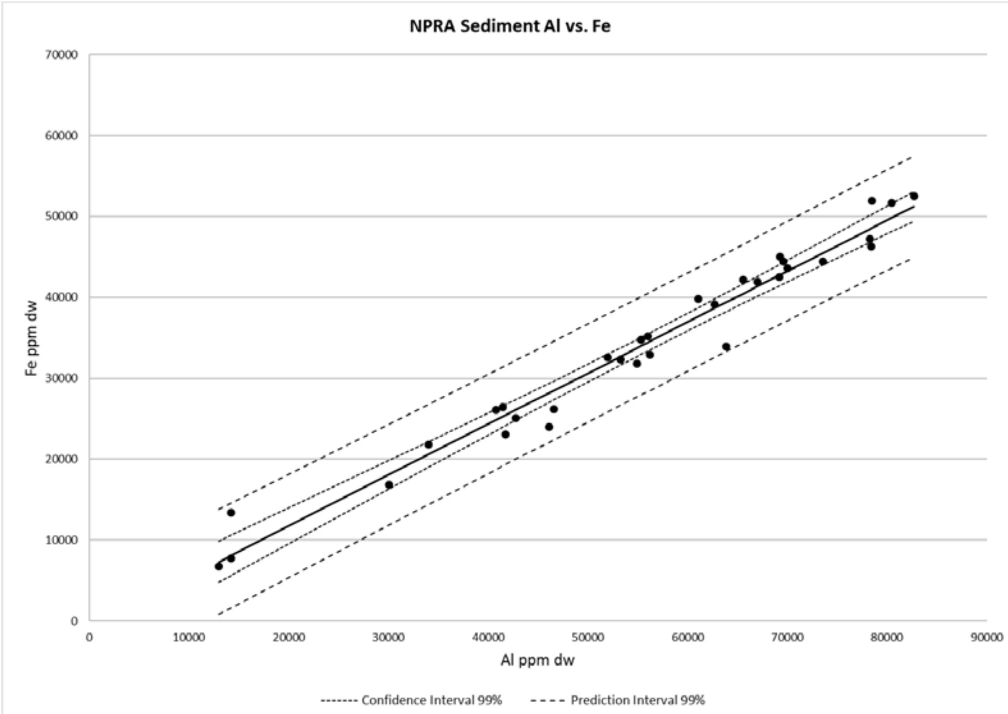

Figure 5. Ordinary least squares regression of surveyed sediments: aluminum versus iron.

A negative relationship between aluminum and silicon is shown in Figure 6. Highly sandy sediments are primarily silica (depending on local geology) and show an inverse relationship between aluminum and silicon. A plot of aluminum and zinc concentrations is shown in Figure 7. There were no extreme outliers to indicate anthropogenic inputs (pollutants) and the data are typical of unimpacted sediments. A plot of aluminum and arsenic is shown in Figure 8. These data were slightly more variable but showed few outliers. Regional differences in arsenic concentrations have been observed in other Alaskan locations (Figure 9; Hartwell et al., 2018). Arsenic appears to be ubiquitous throughout the NPR-A region (Figure 10) with no obvious pattern in elevated concentrations that occurred over multiple estuaries. The concentrations of trace metals measured in this study were comparable to data published by the United States Army Corps of Engineers Alaska District (2007) and Trefry et al. (2003, 2013) for coastal habitats in the Chukchi and Beaufort Seas.

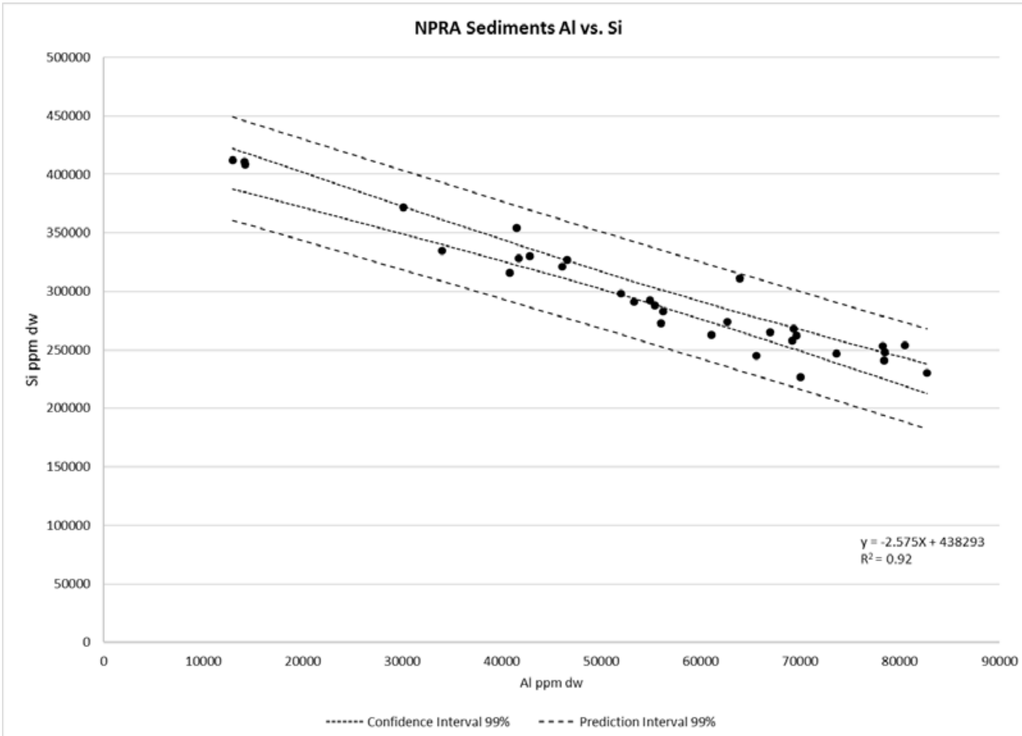

Figure 6. Ordinary least squares regression of surveyed sediments: aluminum versus silicone.

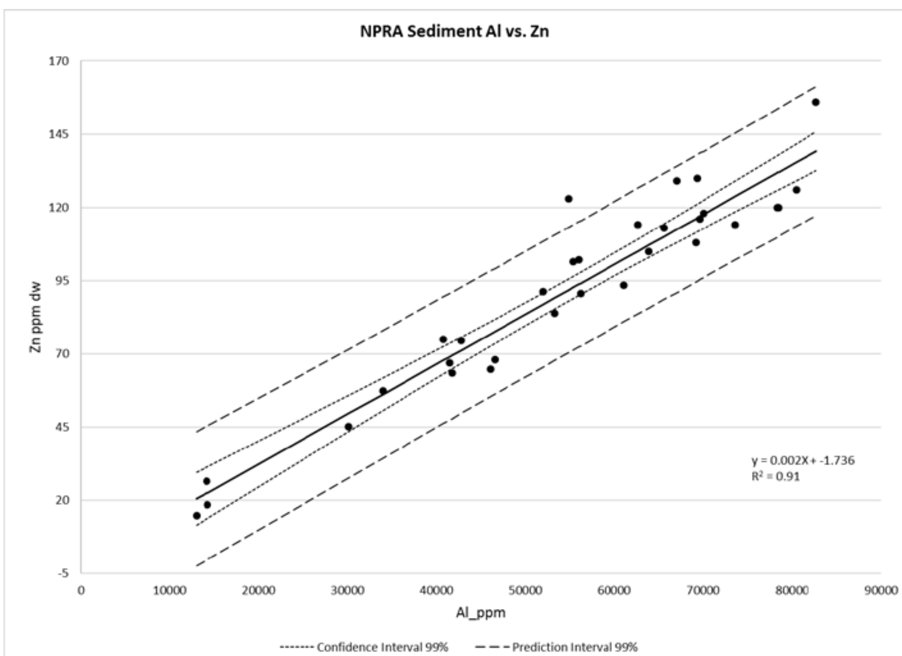

Figure 7. Ordinary least squares regression of surveyed sediments: aluminum versus zinc.

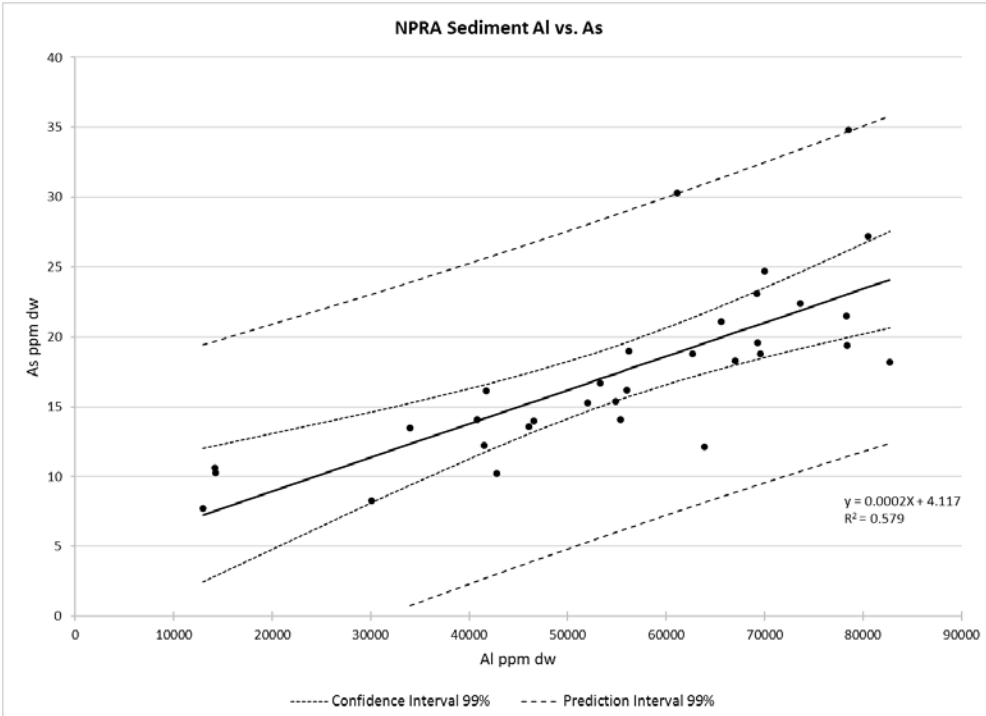

Figure 8. Ordinary least squares regression of surveyed sediments: aluminum versus arsenic.

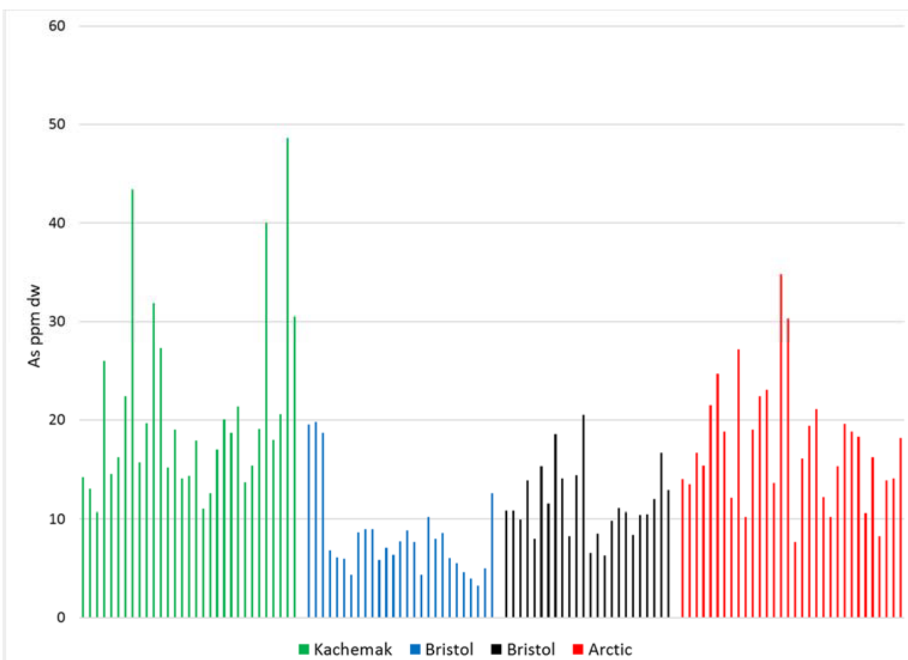

Figure 9. Regional differences in arsenic concentrations in Alaskan coastal sediments (ppm dw).

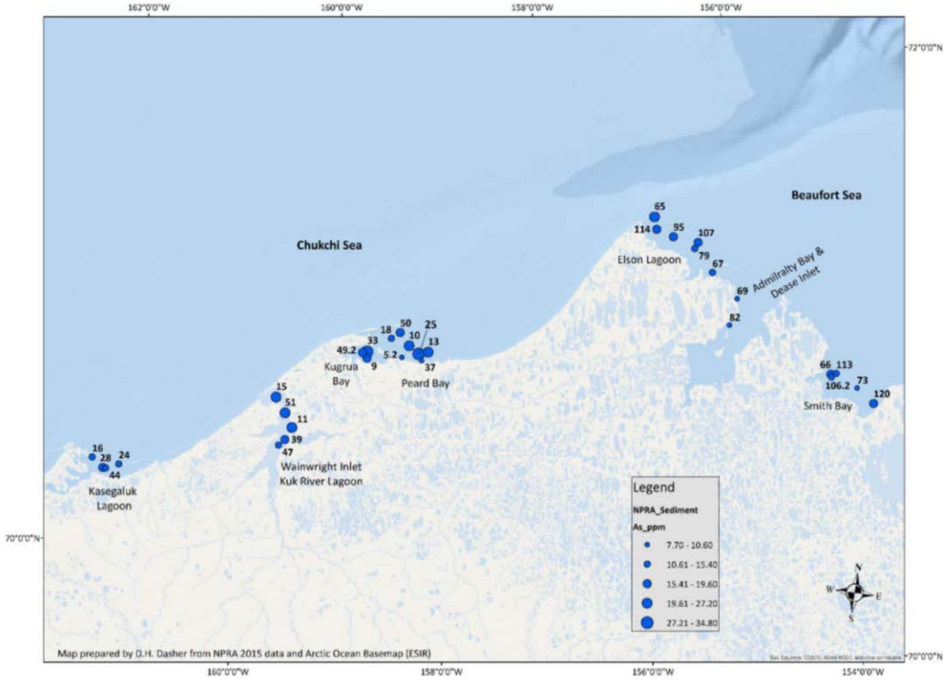

Figure 10. Arsenic concentrations in survey station sediments (ppm dw). Numbers identify stations.

PAHs

Concentrations of PAHs were relatively high for pristine locations; however, petroleum hydrocarbons were not evident. Rather, characteristics of the PAH compounds present indicated large contributions of terrestrial organic matter in the form of peat and coal. The PAH concentrations NPR-A estuary samples were relatively high compared to other Alaskan locations reported in the NOAA National Status and Trends database. Figure 11 shows the mean and range of PAH concentrations in harbors and open water on all three Alaskan coasts (Hartwell et al., 2018). While the concentration of perylene is relatively low, terrestrial sources of organic carbon are an important input in Arctic lagoons (Naidu et al., 2000; Dunton et al., 2006, 2012).

Total PAH concentrations were highly variable between stations (Figure 12), with sandier sediments containing very low concentrations. The contribution of perylene, a natural by-product of decayed vegetation, was relatively low, averaging only 6% in contrast to other locations such as 44% in Kachemak Bay and 29% in Bristol Bay (Hartwell et al., 2009, 2016a). Due to abundant natural coal and peat deposits, the Arctic tundra vegetation and watershed drainage characteristics are far different from further south. Figure 13 shows the PAH concentrations in sediment and peat collected from Smith Bay (Hartwell et al., 2018).

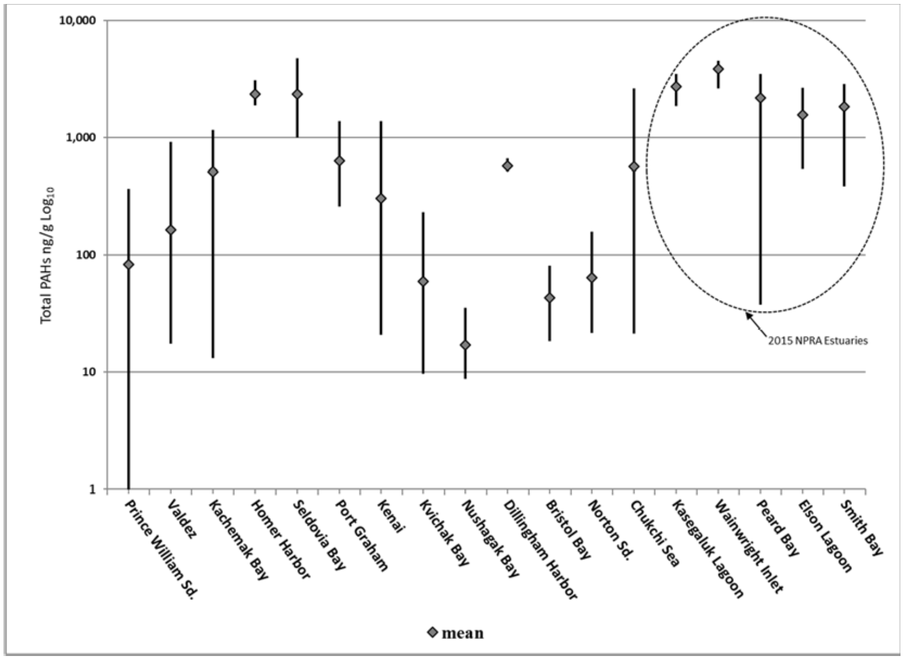

Figure 11. High, low, and mean plot comparing TPAH in Alaska coastal sediments.

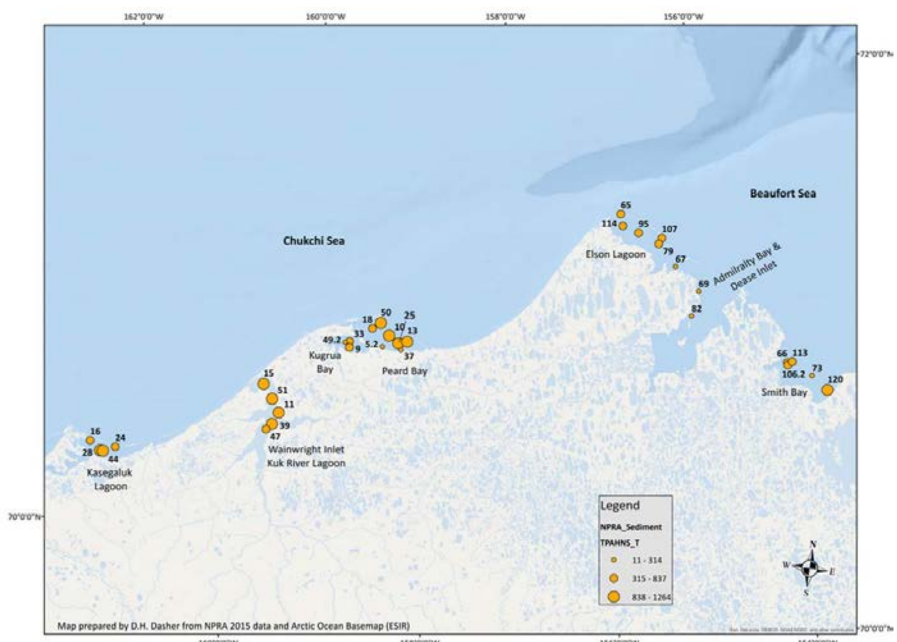

Figure 12. TPAH concentrations in survey station sediments (ppm dw). Numbers identify stations.

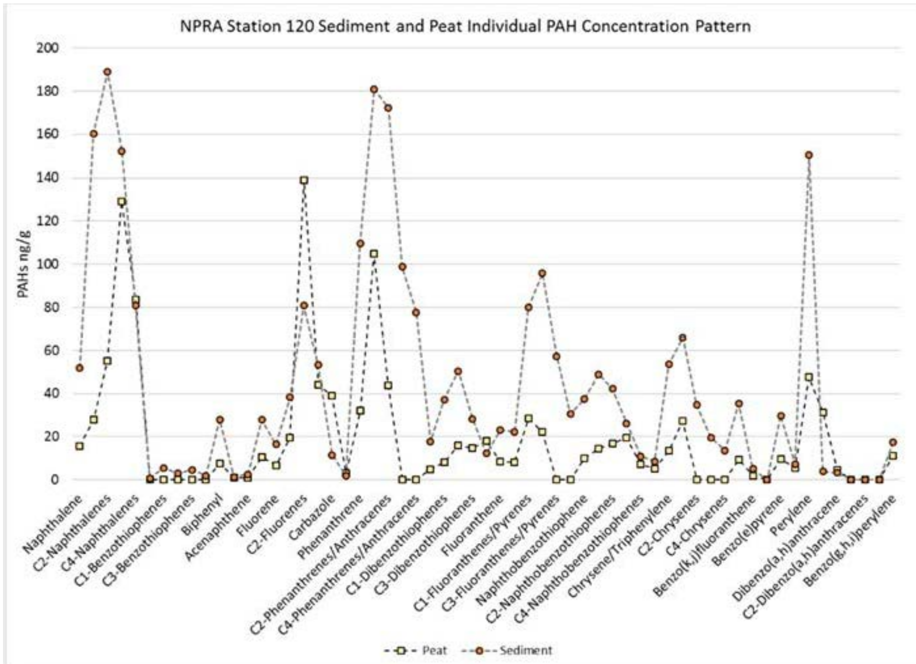

Figure 13. PAH comparison of Smith Bay sediment and reference peat sample.

Figure 14 shows the pattern of individual PAH concentrations in sediment from Kasegaluk Lagoon and coal chips collected in the same sample (Hartwell et al., 2018). Most chemicals were positively correlated with fine-grained sediment ($p < 0.05$) and percent TOC, and negatively correlated with coarse-grained sediment. Depth did not appear to have an impact on these shallow estuaries.

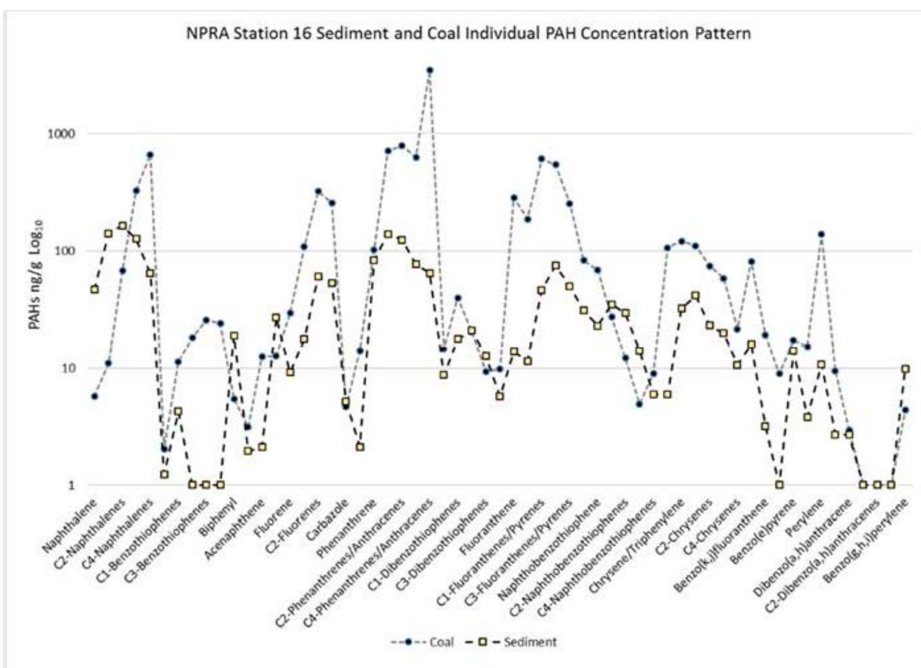

Figure 14. PAH comparison of Kasegaluk Lagoon sediment and reference coal sample.

Macroinvertebrate Samples

Factors influencing the choice of sieve size used in benthic sampling include the study goals, the cost of processing samples, the level of taxonomic identification desired, and the ability to compare data between areas or studies. Multiple authors have shown the influence of using different sieve mesh sizes and that a 1.0-mm screen misses a substantial number of taxa and individuals (Thompson et al., 2003; Barba et al., 2010; Couto et al., 2010; Hammerstrom et al., 2012; Hartwell and Fukuyama, 2015).

In this study, the information gained by macroinvertebrates captured by the 0.5-mm mesh sieves improved estimates of diversity and abundance (Figure 16 and 17). On average, the 0.5-mm sieves captured twice the number of taxa than the 1.0-mm sieves (Figure 18). There was almost an order of magnitude difference in abundance numbers due, in part, to high numbers of specific taxa at selected sampling sites. Diversity values were usually higher in the smaller mesh size, though the difference in biomass was only 15%. These differences may bias interpretation of parameters such as feeding guilds, taxonomic composition of the community, organisms with or without hard parts (shells, carapace), diversity, biomass, dominance, and indicator species. Statistical analysis of the data showed that the smaller sieve size produced a more clear distinction between community traits and the physical habitat drivers that influence them. The 0.5-mm sieve data are superior for assessing and categorizing habitats.

Excluding epiphytic species (hydroids, barnacles, etc.), a total of 18,246 organisms representing 114 taxa were enumerated in the estuarine samples. After eliminating “artificial species” (resulting from failure to identify some specimens all the way down to species), there were 78 taxa and 18,143 organisms. Of these, 17 were rare or unique taxa that occurred at one or two stations. Thus, the final assemblage was comprised of 61 taxa and 18,077 animals distributed over 21 sampling stations. The most numerous taxa were polychaetes, ostracods, oligochaetes, and nematodes. However, the latter three taxa were numerically dominant at only a few stations (≥1,000 individuals) and were present at much lower numbers elsewhere. Polychaetes and arthropod malacostracans were the dominant taxa in terms of diversity, together comprising 47 taxa. Echinoderms (starfish, sea urchins, etc.) were completely absent.

In general, fewer organisms captured in the 0.5-mm sieve could be identified to species than in the 1.0-mm collection. This is a consequence of catching a larger proportion of juveniles, which may not possess adult stage characteristics, and the difficulty in identifying species-specific traits in small specimens. Based on professional judgment using microscope examination, literature, and discussions with taxonomy experts, many of the macroinvertebrates appeared to be young-of-the-year recruits. The distinction between adult and young-of-the-year recruits was also based on the fact that most of the animals present in the 0.5-mm sieves had larger counterparts in the 1.0-mm mesh samples. Sampling late in the growing season will tend to capture the benthic community at peak seasonal development;

however, some species spawn late in the season or repeatedly throughout the season, so juveniles of some species are always present. Also, sieving efficiency can vary seasonally due to settlement pulses that affect the size and composition of samples (Barba et al., 2010).

Taxa were distributed along environmental gradients, so there are generally no distinct boundaries between communities. However, the relationships between habitats and species assemblages reflect the interactions of physical and biological factors and can indicate major ecological trends. Quantitatively, the benthic communities were characterized by abundance, species richness, and diversity, followed by pattern and classification analysis for delineation of taxa assemblages. Abundance was calculated as the total number of individuals per square meter, taxa richness as the total number of taxa represented at a given site, and taxa diversity was calculated with the Shannon-Weiner Index H' (Shannon and Weaver, 1949). Multivariate cluster analysis was employed to group site and species data (Hartwell et al., 2018). The objective was to produce a coherent pattern of association between sites and species. The site and species clusters were also characterized by physicochemical habitat parameters, contaminant concentrations, and other site-specific data. For each species, the parameters were normalized to their abundance at each site.

Benthic macrofauna, communities of polychaetes, crustacean amphipods, crustaceans, mollusks, and other animals living in or on the sediments are sensitive to physical and chemical changes to the sediment and can be good indicators of impacts from human activities. However, seasonal re-colonization limits the usefulness of macroinvertebrates as indicator species in the NPR-A estuaries. At all stations sampled, the young of the year species, those collected on the 0.5-mm sieve, were more abundant (Figure 17) than the adults collected on the 1.0-mm sieve. Overall, the young of the year represented an average 79% of the abundance observed in our samples. These results suggest that the macroinvertebrates (as larvae) move into the estuaries after ice breakup and either die or are advected in the fall before bottom and landfast ice formation (Feder et al., 1976; Broad, 1977; Grider et al., 1977, 1978; Broad et al., 1978).

Estuary Characterizations

Based on macroinvertebrate species composition and site characterizations, each estuary formed distinct clusters, with the exception of stations 82, 67, 120, and 5 (Figure 15). Clustering was related to physicochemical habitat conditions (Harwell et al., 2018). Elson Lagoon and Smith Bay were more alike than they were to Peard Bay and Wainwright Inlet (Kuk River). They were slightly colder with slightly higher bottom dissolved oxygen concentrations. Station 120 in Smith Bay had high salinity, TOC, abundance, number of taxa, and muddy sediments. Station 82 in Admiralty Bay had low salinity, TOC, abundance, number of taxa, and sandy sediments. The only taxon with any significant abundance at Station 82 was Oligochaetes. Unlike the rest of the Elson Lagoon sites, Station 67 is mostly sand and open to the influence of the Beaufort

Sea. Station 5 in Peard Bay is located along the southwestern shore in shallow water and, unlike the rest of the Peard Bay stations, had low TOC, low abundance, low number of taxa**,** and sandy sediments**.** This location contained primarily Ostracoda, with smaller numbers of Oligocheates and Nemotodes. The three stations in Kugrua Bay, an inner embayment to Peard Bay, contained primarily Oligocheates and Ostracoda.

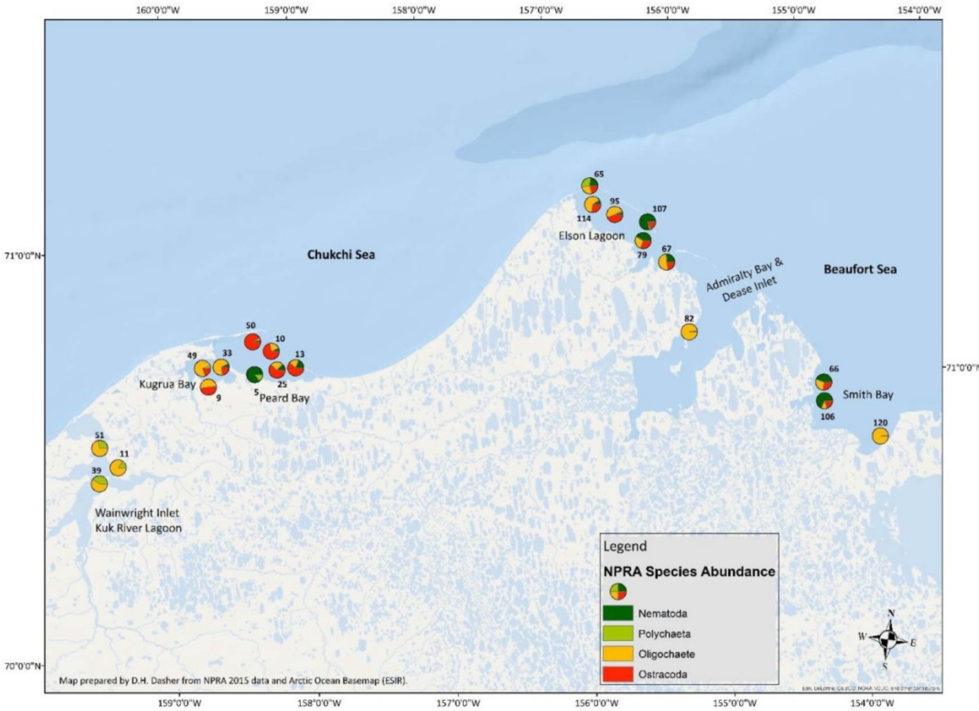

Figure 15. Benthic species abundance at NPR-A estuary survey stations; four main taxa, numbers are station numbers.

As a group, Elson Lagoon stations had, by far, the greatest number of species, followed by Peard Bay. A group of 16 species found in Smith Bay and Elson Lagoon was virtually absent from the Chukchi Sea estuaries. The physicochemical habitats of the NPR-A Beaufort estuaries differ from those of the NPR-A Chukchi estuaries in water temperature, salinity, TSS, and nearshore ice dynamics, so it is expected that they would host species adapted to this environment. Peard Bay sites (including site 5) had a group of nine species that were virtually absent from the other estuaries and a group of seven taxa (found in sandier locations) that were rarely found elsewhere. Except for Peard Bay, the estuaries are all shallow embayments that freeze to the bottom with landfast ice in winter. Located at the head of Barrow Canyon and the confluence of the Bering Sea waters (BSW) and Alaska Coastal Waters (ACW), Peard Bay is oceanographically and biologically unique (OSCEAP, 1985). The region to the northwest of Peard Bay is subject to significant amounts of upwelling of Arctic basin waters (Atlantic waters onto the Chukchi shelf). These environmental conditions may account for the species abundance and diversity observed in Elson Lagoon and Peard Bay.

For more in-depth information regarding general habitat features, sediment chemistry, and trace metal, PAH, and macroinvertebrate results within the individual estuaries, see the NOAA Technical Memorandum *Characteristics of Benthic Habitat and Contaminant Assessment of Arctic Lagoons and Estuaries* (Hartwell et al., 2018). Appendix E provides additional sediment physical, trace metal, and PAH descriptive statistics and data for this survey.

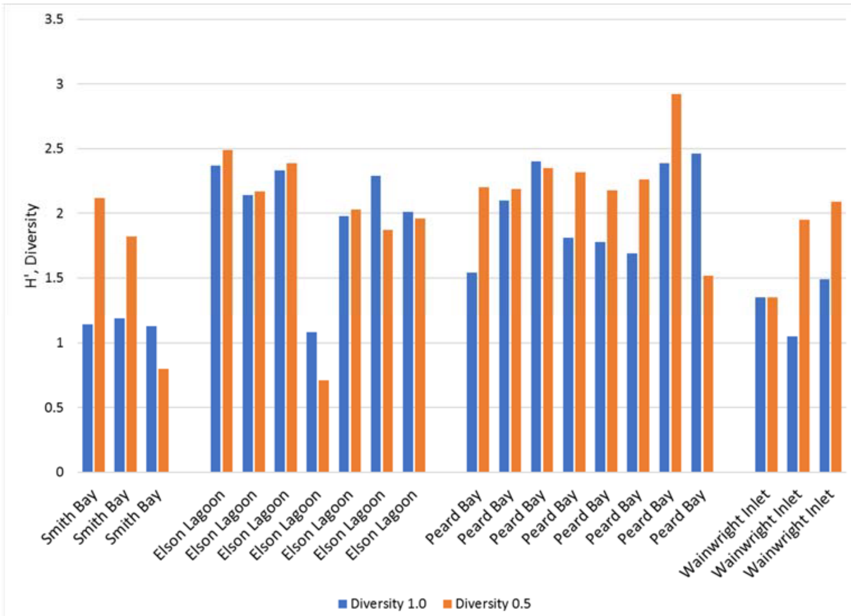

Figure 16. Estuary site comparisons: benthic diversity by sieve size.

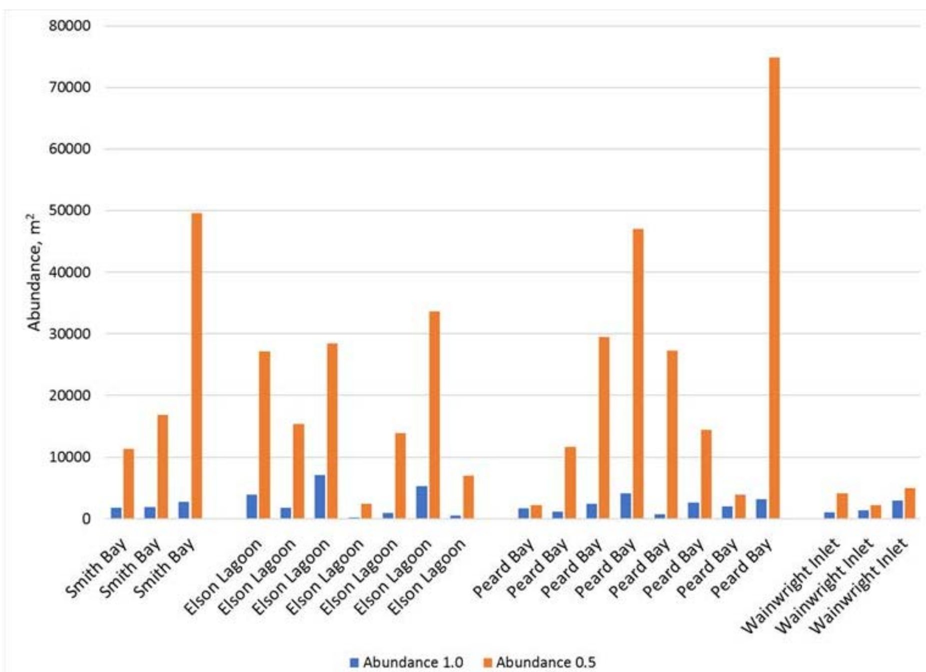

Figure 17. Estuary site comparisons: benthic abundance by sieve size.

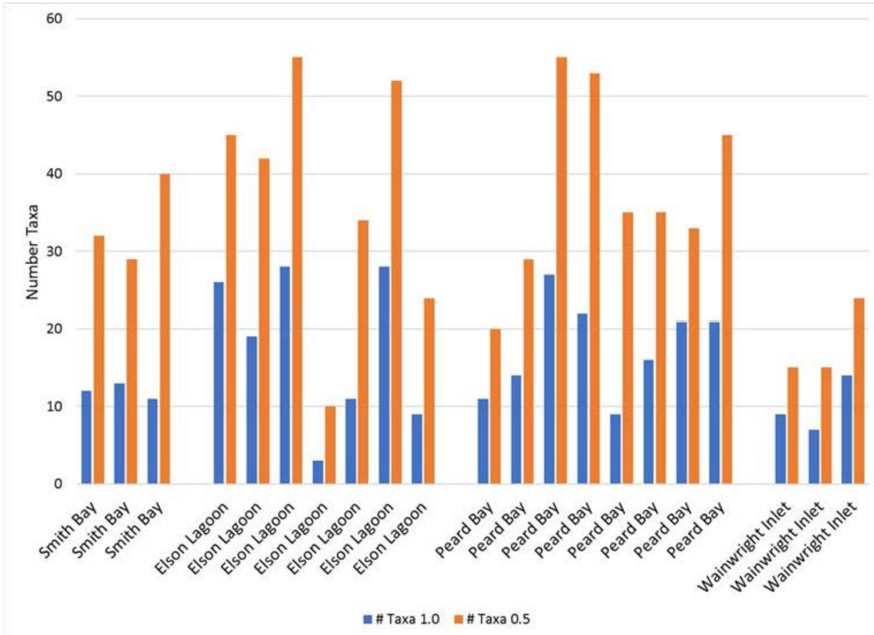

Figure 18. Estuary site comparisons: number of benthic taxa by sieve size.

Fish Samples

Beam trawling was attempted in four estuaries but was only successful in Smith Bay and Peard Bay. Trawl collections yielded very few fish, and those caught were small, so samples were composited by site and species. The National Marine Fisheries Service provided additional fish subsamples from Elson Lagoon. All species collected (Tables 3 and 4) were predators that feed on either benthos or zooplankton and are at the secondary consumer level in the food web. However, they were all young fish and unlikely to have acquired high levels of bioaccumulative substances.

Tissue concentrations of polychlorinated biphenyls (PCB) were relatively low and did not demonstrate any pattern (Table 3). Some fish contained low chlorinated congeners, while others had higher-level congeners, but there was no consistent spatial or species pattern. The concentrations were lower than seen in starry flounder from Naknek and Dillingham (mean: 22.7 ng/g) but higher than levels seen in fish from open water in Nushagak and Kvichak Bays (mean: 4.8 ng/g) (Hartwell et al., 2016a). On average, PCB and cyclodiene (chlordane) concentrations were half those seen in fish from southeast Bristol Bay (Hartwell et al., 2016a).

All samples had detectable hexachlorobenzene (HCB). HCB is banned for use as a pesticide but is still released in small quantities from other chemical manufacturing, industrial processes, incineration, and is residually present from historical use. Highly persistent in the environment and bioaccumulative in lipids, HCB is distributed around the globe by a process termed “global distillation” (Wania and Mackay, 1995), whereby it circulates from warm areas and collects in colder areas, such as the poles, where it has never been used. Cyclodienes (chlordane and related compounds) and hexachlorohexanes (HCH) were seen at low levels in some fish but not all samples. No samples had detectable DDT (dichlorodiphenyltrichloroethane) or its metabolites. These compounds are also subject to global distillation.

Metals concentrations in the fish did not exhibit any pattern (Table 4). There were individual spikes for mercury, copper, lead, and chromium, but there was no spatial or species-specific pattern. A composite sample of slender eelblennies from Elson Lagoon had an anomalously high mercury level, but this was not seen in other species from Elson Lagoon. Arsenic was elevated reflecting higher concentrations in sediment. Whole-body concentrations of As were higher relative to average values found under the Alaska Fish Monitoring Program (DEC, 2018) but nickel was not. Arsenic will accumulate in organisms, but neither As or Ni tend to biomagnify up the food chain (UK Marine SACS, 2001; WHO, 1991). Our fish sample results for the NPR-A estuaries are comparable to average tissue levels seen in Bristol Bay starry flounder (*Platichthys stellatus*) and rainbow smelt (*Osmerus mordax*) from Nushagak and Kvichak Bays (6.68 and 3.35 ug/g, respectively) (Hartwell et al., 2016a). Whole-body arsenic body burdens in fish from Chrome Bay on the Kenai Peninsula averaged 1.33 ug/g (Hartwell et al., 2016b). Although not strictly comparable, liver and muscle tissue in salmon returning to Kachemak Bay after years in the open North Pacific Ocean contained an average of 1.14 ug/g arsenic (Apeti et al., 2013).

Table 3. Organic contaminants detected in NPR-A estuary fish, ng/g (ppb) dw.

Species	**Location**	**# Composite**	**wt (gm)**	**% Lipid (dry)**	**Total PCBs**	**Cyclodienes**	**Total HCH**	**Hexachlorobenzene**
Slender eelblenny	Peard Bay	30	11.30	6.57	3.23			0.89*
Arctic flounder	Peard Bay	1	50.70	13.55			1.46	1.56
Arctic cod	Smith Bay	3	26.20	27.08	14.18	3.88	1.62	5.62
Arctic sculpin	Smith Bay	6	11.00	11.08			1.83	1.43
Fourhorn sculpin	Elson Lagoon	2	27.00	6.79	16.03		1.53	1.14
Arctic cod	Elson Lagoon	4	51.70	18.22	17.38	1.11		8.44
Fourhorn sculpin	Elson Lagoon	4	155.30	9.95	1.06	0.97		1.66

*below the method reporting limit

Table 4. NPR-A fish whole-body trace metal concentrations and DEC reference samples, ug/g (ppm) dw.

Species	**Site**	**Ag**	**As**	**Ba**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Sn**	**Zn**
Slender eelblenny	Peard	0.08	6.13	5.48	0.22	1.69	4.71	0.06	1.47	0.46	2.32	0.09	124.00
Arctic flounder	Peard	0.06	11.50	1.57	0.16	0.52	2.94	0.11	0.93	0.10	3.08	0.04	94.30
Shorthorn Sculpin	Peard	0.07	4.57	7.64	0.41	13.40	6.04	0.05	2.55	0.73	2.01	0.04	107.00
Arctic cod	Smith	0.07	8.74	3.52	0.47	0.51	7.64	0.07	0.97	0.12	3.28		82.00
Arctic sculpin	Smith	0.09	4.30	8.44	0.15	2.86	8.41	0.05	1.53	0.52	2.98	0.08	82.80
Arctic cod	Elson	0.02	2.55	13.90	0.59	0.54	2.39	0.04	0.60	0.60	2.27	0.04	122.00
Fourhorn sculpin	Elson	0.13	5.05	7.47	0.12	14.20	14.10	0.08	1.44	0.27	3.81	0.09	71.50
Arctic cod	Elson	0.07	10.70	7.93	0.26	1.48	5.00	0.03	1.62	0.43	3.45	0.21	81.30
Fourhorn sculpin	Elson	0.13	6.02	10.30	0.23	1.03	101.00	0.26	7.58	3.12	2.79	0.27	132.00
Slender eelblenny	Elson	0.12	4.98	4.33	0.37	1.07	7.81	1.19	1.01	0.37	3.27	0.08	65.70
	DEC Alaska Fish Monitoring Program reference samples												
Arctic Flounder	n.d.		6.40			1.24	2.23	0.08	1.75				
Arctic Sculpin	n.d.		3.40		0.07	1.20	4.00	0.09	2.56				
Fourhorn Sculpin	n.d.		3.34			4.80	3.90	0.20	2.81				

Results and Discussion: Assessment and Condition Indexing

NPR-A estuary survey NCCA reporting is based on ecological indices and component indicators used to analyze the project datasets. This section describes the environmental condition of the NPR-A estuaries and the indices, component indicators, and cutpoints used in developing the water quality rankings of good, fair, or poor.

Environmental Condition Assessment

The overall environmental condition assessment for the NPR-A estuary survey was based on water and sediment quality indices with their component indicators (Table 5). Relative rankings of good, fair or poor of component indicators were based on comparisons to cutpoints developed from DEC water quality standards and/or other numeric criteria. The condition assessment provides probability-based estimates of the percent area of the target population surveyed for particular ecological status defined by measured values of assessment indicators. Table 6 defines the overall regional water quality ranking indices.

Results of the benthic macroinvertebrate and fish tissue contaminant sampling are discussed in more general terms because a limited number of fish were captured and no DEC benthic macroinvertebrate criterion exists for Alaska's coastal waters. Neither of these indicators was used in estimating overall area environmental condition.

Table 5. Description of indices and component indicators

Index	**Source**
Water Quality Index	Professional judgment, existing Chukchi Sea nutrient and chlorophyll *a* data, and DEC Water Quality Standards.
Sediment Quality Index	DEC Water Quality Standards and professional judgment.
Component Indicator	**Source**
Nitrate as Nitrogen (NO3-N mg/l) Phosphate as Phosphorus (PO4-P mg/l) Chlorophyll *a* (µg/l)	No DEC Water Quality Standards. Compared with criteria used for nutrient and chlorophyll *a* data for Chukchi Sea waters in previous AKMAP survey.
Dissolved Oxygen (DO) mg/l	DEC Water Quality Standards
Sediment Contaminants	Long et al., 1995.
Sediment Total Organic Carbon (TOC %)	U.S. EPA National Condition Assessment Report

Table 6. Regional water quality ranking index.

Ecological Condition by Site	Ranking by Region
Good: No component indicators are rated poor, and a maximum of one is rated fair.	**Good:** Less than 10% of the coastal area is in poor condition, and more than 50% of the coastal area is in good condition.
Fair: One component indicator is rated poor, or two or more component indicators are rated fair.	**Fair:** Between 10% and 20% of the coastal area is in poor condition, or 50% or less of the coastal area is in good condition.
Poor: Two or more component indicators are rated poor.	**Poor:** More than 20% of the coastal area is in poor condition.

NPR-A Estuary Water Quality

The DEC Alaska Water Quality Standards (AWQS) regulate human activities that result in alterations in waters within the state's jurisdiction (DEC, 2015). These standards are based on an anti-degradation policy that "…existing water uses and the level of water quality necessary to protect existing uses must be maintained and protected." Standards are defined for each marine water use class and subclass and for marine water. Generally, water quality standards fall into three categories: absolute threshold concentrations, concentration ranges, and limitations to the change that can be made above or below a natural background or reference condition. When AWQS exist for a particular indicator, comparisons of the study area that do not meet that standard will be presented. In other cases, where AWQS have not been defined, other applicable comparison values, such as Effects Range Low (ERL) and Effects Range Median (ERM), will be discussed.

Four component indicators comprise the water quality index: dissolved oxygen, chlorophyll *a*, dissolved phosphate, and dissolved nitrate. The DEC does not have numeric water quality standards for nutrients (phosphate/nitrate) or chlorophyll *a* in marine waters (DEC, 2015), so these cutpoints were developed from a dataset (Hartwell et al., 2018) representing pelagic Chukchi Sea nutrient and chlorophyll *a* concentrations (Dasher et al., 2015). A total of 237 dissolved nitrate, 241 dissolved phosphate, and 177 chlorophyll *a* concentrations were used to develop the nutrient and chlorophyll *a* cutpoints. Cutpoints are based on upper confidence levels (UCL) of 90% and 99%. The nutrient and chlorophyll *a* concentrations $< 90\%$ were selected to represent good, values between the good cutpoint and 99% UCL were ranked fair, and $> 99\%$ was ranked poor. The Pro-UCL statistical software was used to calculate the 90% and 99% nonparametric UCLs (U.S. EPA, 2016). Dissolved oxygen cutpoints were based on the DEC water quality standards numeric criteria for marine waters (DEC, 2015). Resulting indicator cutpoints are shown in Table 7.

Table 7. Description of cutpoints for nutrients, chlorophyll *a* and dissolved oxygen.

Parameter	**Good**	**Fair**	**Poor**
Nitrate Nitrogen as Nitrogen (NO3-N mg/l)	≤ 0.08	> 0.08–≤0.12	> 0.12
Phosphate as Phosphorus (PO4-P mg/l)	≤ 0.13	> 0.13–≤ 0.23	> 0.23
Chlorophyll *a* (Chl *a* ug/l)	≤ 3.97	> 3.97–≤ 6.39	> 6.39
Dissolved Oxygen (DO mg/l) Surface (1 m)	≥ 6–≤17	≥ 5–< 6	< 5
Dissolved Oxygen (DO mg/l) Bottom	≥ 6–≤ 17	≥ 5–< 6	< 5

NPR-A Overall Water Quality Index

The water quality index for the NPR-A estuary survey area is good (Figure 19). The condition of the NPR-A estuary area is good for dissolved NO_3-N and PO_4-P. Surface and bottom dissolved oxygen concentration conditions for the NPR-A estuary survey area are also rated good and results met DEC Alaska Water Quality Standards (AWQS) criteria for all marine water uses including harvesting mollusks or other raw aquatic life and the aquaculture, growth, and propagation of fish, shellfish, and other aquatic life and wildlife. The chlorophyll *a* condition for the NPR-A estuary survey area is rated good to fair, with 94 % good and 6% fair. Only two stations (009, 033) in Kugra Bay, an inner bay to Peard Bay, ranked as fair. Given the small human population and lack of identified anthropogenic sources of nutrients near the stations, the observed fair values likely reflect natural conditions rather than direct human influences.

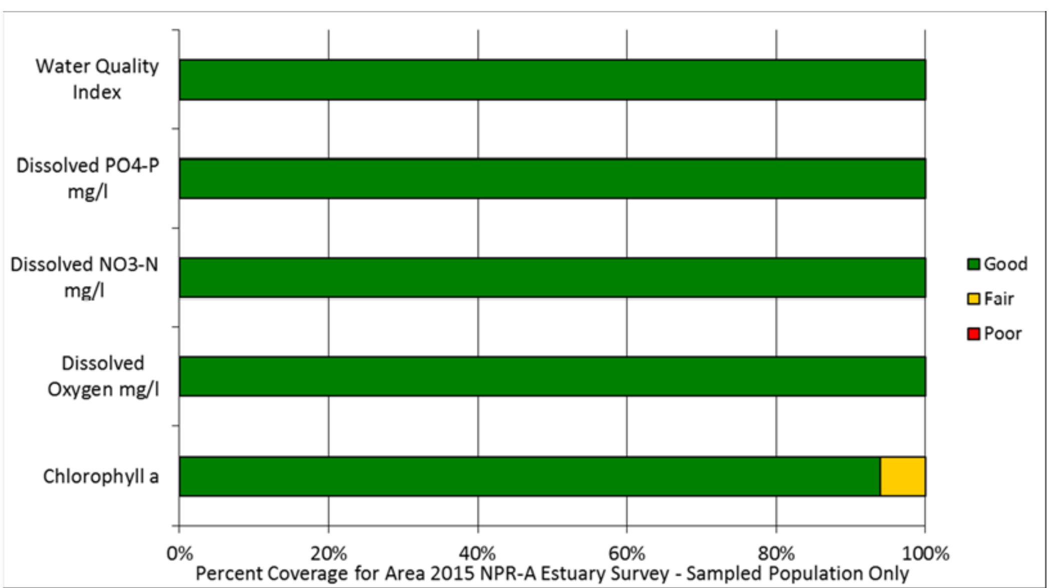

Figure 19. NPR-A estuary survey 2015 water quality index.

NPR-A Estuary Sediment Quality

The sediment quality index is comprised of two component indicators: sediment contaminants and total organic carbon.

Sediment contaminants component

There are no absolute contaminant concentrations that correspond to sediment toxicity, but Effects Range Low (ERL) and Effects Range Median (ERM) values (Long et al., 1995) were used as guidelines in assessing sediment contamination. ERM is the median concentration (50th percentile) of a contaminant observed to have adverse biological effects in the literature studies examined. The ERL is a more protective indicator of contaminant concentration and represents the 10th percentile concentration of a contaminant demonstrated to have adverse biological effects in peer-reviewed studies.

Nine trace metals analyzed in this survey have published ERL and ERM concentration benchmarks. ERL was exceeded for As, Cr, Cu, Ni, and Zn, but no ERM values were exceeded. (Table 8). Sediment concentrations for the trace metals were within the ranges observed in previous studies (Valette-Silver et al., 1999; Trefry et al., 2003; Naidu et al., 2012; Dasher et al., 2015). Arsenic and Ni concentrations in marine sediments may naturally exceed the ERL because of input from seawater, coastal rivers, and regional crustal geology (Maher and Butler, 1988; Lauenstein et al., 2000).

Table 8. Comparison of sediment trace metal concentrations with ERL and ERM values.

		Benchmarks		**Sample Results Range**	**% of Sites**	
	n	**ERL**	**ERM**		**< ERL**	**≥ ERL–ERM**
Trace Metal	**μg/g dw (ppm)**					
Arsenic	32	8.2	70	7.7–34.8	3.1	96.9
Cadmium	32	1.2	9.6	0.031–0.187	100	0
Chromium	32	81	370	13.85–104	78.1	21.9
Copper	32	34	270	4.71–60.6	71.9	28.1
Lead	32	46.7	218	4.38–20.6	100	0
Mercury	32	0.15	0.71	0.003–0.088	100	0
Nickel	32	20.9	51.6	6.61–55.5	12.5	84.4
Silver	32	1	3.7	0.051–0.168	100	0
Zinc	32	150	410	14.7–156	96.9	3.1

For polycyclic aromatic hydrocarbons (PAHs), only fluorene and 2-Methylnaphthalene had exceedances of their respective ERLs, and no PAHs exceeded ERM values (Table 9). Sediments were not analyzed for PCBs or chlorinated pesticides due to a history of extremely low levels (often below detection concentrations) in previous studies (Valette-Silver et al., 1999).

Table 9. Comparison of sediment PAH concentrations with ERL and ERM values.

	N	Benchmarks		Sample Results Range	% of Sites	
		ERL	ERM		< ERL	≥ ERL–ERM
PAH ng/g dw (ppb)						
Acenaphthene	32	16	500	0.05–8.98	100	0
Acenaphthylene	30	44	640	0.02–1.66	100	0
Anthracene	31	85.3	1,100	0.028–3.15	100	0
Fluorene	32	19	540	0.52–90.7	71.9	28.9
2-Methylnapthalene	32	70	670	0.732–256.6	34.4	65.6
Naphthalene	32	160	2,100	0.40–83.93	100	0
Phenanthrene	32	240	1,500	1.31–156	100	0
Benz(a)anthracene	32	261	1,600	0.28–34.09	100	0
Benzo(a)pyrene	32	430	1,600	0.16–22.88	100	0
Chrysene	32	384	2,800	0.812–74.6	100	0
Dibenzo(a,h)anthracene	32	63.4	260	0.10–9.70	100	0
Fluoranthene	32	600	5,100	0.23–37.6	100	0
Pyrene	32	665	2,600	0.38–58.74	100	0
Total PAHs	32	4,022	44,792	5.09–634.2	100	0
Low molecular-weight PAHs	32	552	3,160	2.79–517.1	100	0
High molecular-weight PAHs	32	1,700	9,600	2.31–290.7	100	0

Table 10 provides the sediment rating cutpoints for individual sampling sites. The sediment contaminants component indicator for the NPR-A estuary area is rated good to fair, with 84% good and 16 % fair. Typically, a combination of As, Cr, Cu, Ni, fluorene, and 2-Methylnaphthalene contributed to the fair ranking. Arsenic and Ni, considered to be naturally occurring, exceeded the ERL at all five stations. Overall, five stations had five or more contaminants exceeding ERL values, which resulted in the 16% fair rank: two stations in Peard Bay (025, 050), two stations in Wainwright Inlet (015, 051), and one station in Elson Lagoon (114).

Table 10. Sediment ranking cutpoints based on ERL and ERM.

Ecological Condition by Site	Ranking by Region
Good: No sediment contaminant concentrations exceed the ERM, and fewer than 5 contaminant concentrations exceed the ERL.	**Good:** Less than 5% of the coastal area is in poor condition.
Fair: No contaminant concentrations exceed the ERM, and 5 or more contaminants exceed the ERL. concentration is between 2% and 5%.	**Fair***:* 5% to 15% of the coastal area is in poor condition.
Poor: At least one contaminant concentration exceeds the ERM.	**Poor:** More than 15% of the coastal area is in poor condition.

Sediment total organic carbon component

Sediment total organic carbon (TOC) enrichment can be altered in areas where there is considerable deposition of organic matter. If there are pollution sources nearby, these depositional sites are likely to be hot spots for contaminated sediments. Although TOC exists naturally in coastal sediments and is the result of the degradation of autochthonous and allochthonous organic materials (e.g., phytoplankton, leaves, twigs, dead organisms), anthropogenic sources (e.g., organic industrial wastes, sewage) can considerably elevate the TOC concentrations in sediments. Total organic carbon in coastal sediments is often a source of food for benthic organisms, and high levels can result in notable changes in benthic community structure, including the dominance of pollution tolerant species (Pearson and Rosenberg, 1978; Hyland et al., 2005). Increased levels of sediment TOC can also reduce the general availability of organic contaminants (e.g., PAHs, PCBs, pesticides); however, increases in temperature or decreases in dissolved oxygen levels can result in the release of these TOC-bound and unavailable contaminants.

The total organic carbon (TOC) component indicator for the NPR-A estuary area was rated good to fair, with 35% good and 65% fair. Seven stations in Peard Bay (009, 010, 013, 025, 033, 049, 050), five in Wainwright Inlet (011, 015, 039, 049, 051), four in Elson Lagoon (065, 095, 107, 114), three in Smith Bay (066, 106, 113), and one in Kasegaluk Lagoon (028) made up the 20 stations ranking fair for TOC. Table 11 provides the cutpoints for rating sediment TOC at individual sampling sites and the regional ranking criteria.

Table 11. Sediment TOC ranking cutpoints.

Ecological Condition by Site	Ranking by Region
Good: Sediment TOC concentration is less than 2%.	**Good:** Less than 20% of the coastal area is in poor condition.
Fair: Sediment TOC concentration is between 2% and 5%.	**Fair:** Between 20% and 30% of the coastal area is in poor condition.
Poor: Sediment TOC is greater than 5%.	**Poor:** More than 30% of the coastal area is in poor condition.

NPR-A Overall Sediment Quality Index

Table 12 provides the cutpoints for rating overall sediment quality at individual sampling sites and the regional ranking criteria. The sediment quality index for the NPR-A estuary area is good (Figure 20). The overall sediment quality index for the estuary area surveyed was 84% good and 16% fair. More weight was given to sediment contaminant results than TOC in determining the final ranking.

Table 12. Regional sediment quality ranking index cutpoints.

Sediment Quality Index by Site	Ranking by Region
Good: None of the individual component indicators is rated poor, and the sediment contaminants indicator is rated good.	**Good:** Less than 5% of the coastal area is in poor condition, and more than 50% of the coastal area is in good condition.
Fair: None of the component indicators is rated poor, and the sediment contaminants indicator is rated fair.	**Fair:** 5% to 15% of the coastal area is in poor condition, or more than 50% of the coastal area is in combined poor and fair condition.
Poor: One or more of the component indicators is rated poor.	**Poor:** More than 15% of the coastal area is in poor condition.

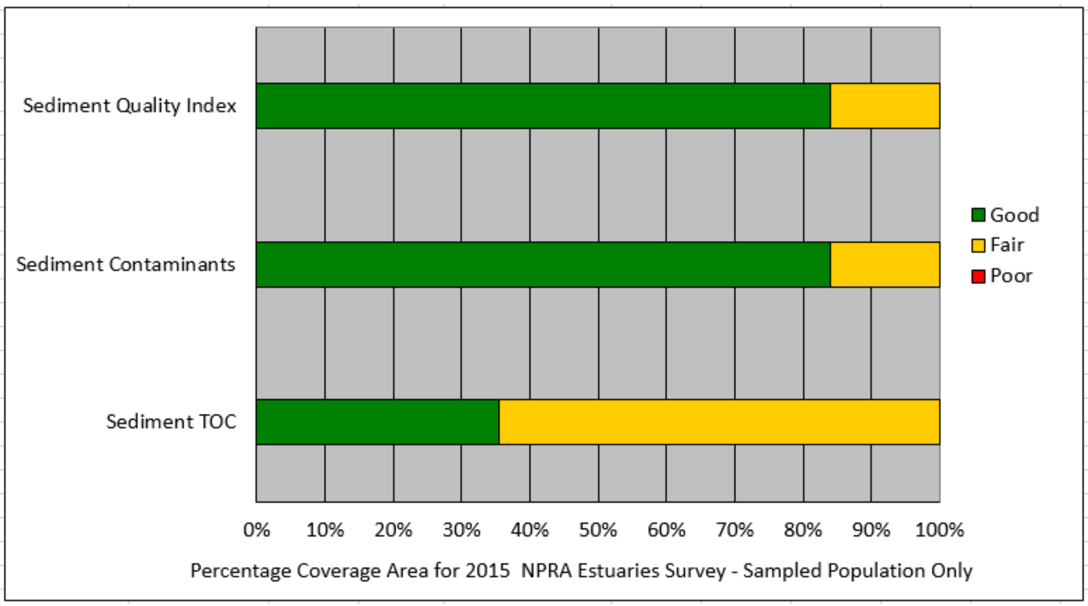

Figure 20. NPR-A estuary survey sediment quality index.

Sampled Population Environmental Condition

Condition ranking for the AKMAP Survey coastal nearshore waters was calculated by summing the scores for the overall water quality and sediment indices and dividing by the number of available indices, where good is ≥ 90%; fair is 90% to 50%, and poor is < 50%. The overall environmental condition for the NPR-A estuary area is good (Figure 21). The overall quality index was rated as good over 92% of the estuary area surveyed and 8% as fair. Principal component indicator drivers for the fair index rating were As, Ni, TOC, and chlorophyll *a*.

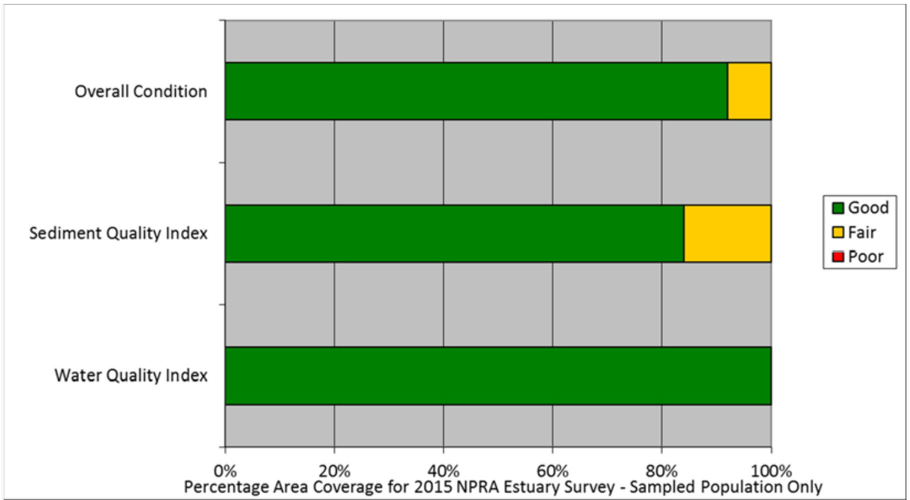

Figure 21. NPR-A estuary survey overall quality index.

Benthic Habitat Condition

Benthic macrofauna, communities of polychaete, crustacean amphipods, crustaceans, mollusks, and other animals living in or on the sediments, are sensitive to physical and chemical changes to the sediment. Because of this sensitivity, these macrofauna can be good indicators of impacts from human activities. Alaska Water Quality Standards have not adopted indices of benthic community condition that can be used for ranking (DEC, 2015). However, studies in Port Valdez and Norton Sound provide a basis for interpreting benthic community characteristics for responses to anthropogenic stressors (Blanchard et al., 2015).

It was not possible to use macroinvertebrate results in rankings because there are no benthic community condition indices in the Alaska Water Quality Standards. Additionally, sampling success was limited, and only 21 sites were successfully sampled: three of five sites in Wainwright Inlet; eight of ten sites in Peard Bay; seven of eight sites in Elson Lagoon; and three of five sites in Smith Bay. Many stations consisted of hard-packed silty sand that the sampler could not penetrate deeply enough to collect enough mass for a valid sample. Four of the sites in Kasegaluk Lagoon could be sampled for chemical analyses, but adequate benthos samples were not obtained.

Fish Tissue Evaluation

Demersal fish live in close contact with the sediments and are considered good indicators of contaminants in the sediments (Elliott et al., 1988). Seven whole fish were analyzed for hydrocarbons and organochlorines (Table 3), and ten fish were analyzed for trace metals (Table 4).These fish represent an important component in the estuary food web for marine mammals, such as seals. In the absence of standardized indices, the EPA risk-based advisory guidance values for recreational fishing (Table 13; U.S. EPA, 2008) were used to assess the fish health.

Although regional rankings of fish tissue contaminants were not possible due to low sample sizes, contaminant analyses were still informative. In comparison with the benchmarks (Table 13), the sampled fish contaminant concentrations are considered good. Only the benchmark mercury (Hg) level was exceeded with a concentration of 0.28 ppm wet weight for a slender eelblenny taken in Elson Lagoon. No other benchmark level exceedances occurred. Fish were also analyzed for tributyltin, which is an antifouling paint toxic to marine life and now banned in the United States. Tributyltin was not detected in any of the fish tissue samples.

Table 13. EPA guidance used in assessing fish health (U.S. EPA, 2008). Range of concentrations associated with health risk for consumption of four 8-ounce fish portions a week. U= not detected; J= detected below method of detection or reporting limit.

Contaminant	EPA Advisory Guidance Range (μg/g wet weight)[a]	Tissue Range Min–Max (ug/g wet weight)	Health Endpoint Used
Trace Metals			
Arsenic (inorganic)[a]	0.35–0.70	0.0.012–0.055[a]	non-cancer
Cadmium	1.2–2.3	0.027–0.140	non-cancer
Mercury[b]	0.12–0.23	0.007–0.282	non-cancer
Selenium	5.9–12.0	0.476–0.903	non-cancer
Organochlorine Pesticides & PCBs			
Total Chlordane	0.59–1.2	0.00001(J)–0.0010	non-cancer
Total DDT	0.59–1.2	U–0.0002(J)	non-cancer
Dieldrin	0.059–1.2	U–0.0001(J)	non-cancer
Endosulfan II	7.0–14.0	U	non-cancer
Endrin	0.35–0.70	U	non-cancer
Heptachlor epoxide	0.015–0.031	U–0.0002	non-cancer
Hexachlorobenzene	0.94–1.9	0.0002(J)–0.0019	non-cancer
Lindane	0.35–0.70	U–0.0004	non-cancer
Mirex	0.23–0.47	U	non-cancer
Total PCBs	0.023–0.04	U–0.004	non-cancer
PAHs			
benzo(a)pyrene	0.0016–0.0032	U	cancer[c]

a) Laboratory results for fish were in dry weight. Dry weight was converted to wet weight values using lab-reported moisture content for tissue samples. Inorganic arsenic concentrations were estimated to be 2% of total arsenic concentrations.

b) The conservative assumption was made that all mercury is present as methylmercury.

c) A non-cancer concentration range for PAHs does not exist.

Reference Condition

These NPR-A estuary survey results reflect reference conditions in the region. Reference condition describes natural conditions in an ecosystem that is minimally affected by human disturbances (Stoddard et al., 2006). Reference conditions are used by environmental managers to develop site-specific water quality criteria used for establishing standards or benchmarks for specific water bodies (Russo, 2002; Borja et al., 2012). While NPR-A estuaries are not isolated from all human disturbances, they remain relatively pristine, and rankings must be considered in light of the reference condition of the survey area. The rankings allow for comparisons to DEC water quality standards or other derived indices; however, a fair or poor ranking does not necessarily represent impact from human disturbances. The poor or fair rankings examined in this report appear to be related to natural rather than anthropogenic factors and demonstrate the need to develop water quality criteria specific to the Arctic estuaries. One goal of the AKMAP surveys is to build a dataset that DEC can use to establish appropriate regional water quality criteria.

The entire estuary study area meets the NPR-A DEC water quality standards or other derived index for nutrient and dissolved oxygen concentrations. Though 94% of the estuary area ranked good, high phytoplankton biomass (measured as chlorophyll *a)*, which can be a symptom of degraded water quality, resulted in a 6% fair ranking. Given shallow estuaries, the late summer season, and coastal watershed nutrient inputs, it was not unexpected that a few NPR-A estuary chlorophyll *a* values were ranked fair. Further, due to the lack of historical chlorophyll *a* data, the NPR-A estuary survey used a chlorophyll *a* index developed for the AKMAP Chukchi Sea survey. Overall, the water column data for the surveyed NPR-A estuaries for nutrients, DO, and chlorophyll *a* represent a reference condition for late summer conditions.

NPR-A estuary survey water column and sediment results appear to reflect reference or baseline conditions for the region. Contaminants, such as PCBs and other organochlorine pesticides, are transported to the region by the atmosphere and, to a lesser degree, ocean currents. Vessels, villages, and former defense sites are potential sources of pollutants, though they have not been documented as contributing significant contamination to the regional estuary sediments or waters. As of 2018, the NPR-A estuaries have no identified significant sources of contaminants.

Arsenic and Ni concentrations, which drove the sediment contaminants ranking of fair, represent natural inputs (Naidu et al., 2012). The coastal erosion of permafrost contributes significant quantities of organics, in the form of peat and coal, which drove the fair ranking for TOC component (Jorgenson et al., 2005; Asahara et al., 2012). Similarly, sediment hydrocarbon data are representative of natural sources rather than from oil and gas extraction operations (Venkatesan et al., 2013). Overall, the sediment data for the surveyed NPR-A estuaries for trace metals, hydrocarbons, and TOC represent a reference condition for late summer conditions.

While results of the NPR-A sediment chemistry offers no evidence that the benthic habitat is currently impacted by human activities (Blanchard et al., 2015), the results of the benthic macroinvertebrate sampling suggested that environmental conditions, especially bottom and landfast ice, place high stress on animals living in the sediments.

Conclusions

NPR-A estuaries surveyed represent an ecosystem that, in 2015, was minimally affected by human disturbances, thus establishing a reference condition for long-term monitoring. Overall, a 100% of the sampled region was ranked good, with a small group of fair rankings principally driven by naturally occurring As, Ni, TOC, and chlorophyll *a* levels that exceeded non-regional water quality standard cutpoints. For example, within the water and sediment index, chlorophyll *a*, sediment contaminants, and TOC received some fair rankings. The small group of chlorophyll *a* samples that ranked fair was assessed as naturally resulting from the shallow estuarine environment. As and Ni concentrations, which drove the sediment contaminant fair rank component, were representative of natural coastal sediment rather than anthropogenic inputs. TOC samples that fell into fair ranking were assessed to be a contribution of coastal erosion of permafrost. The results of this first NPR-A estuary survey provide a starting point for developing DEC Water Quality Standards rankings that reflect regional conditions.

Generally, macroinvertebrates and demersal fish living in or on the sediments are considered good indicators of physical and chemical changes to their habitat. However, sampling challenges, ice dynamics and the fact these organisms have limited estuary residency limit their usefulness for environmental monitoring within the NPR-A estuaries. Monitoring sediments and water for physical and chemical changes is likely a better approach to assessing anthropogenic impacts as development continues in the region.

Study Limitations

As the first NPR-A estuary survey, this work provided a snapshot of the environmental conditions for the late summer period for a single year and important reference information for future monitoring. Trends in environmental condition can only be identified through multiple surveys. The data collected and indices used in this study facilitate application of the DEC Water Quality Standards and other criteria developed during regional surveys and may not address all of the environmental issues of concern to Alaskans.

With unsheltered exposure to major storms, a high rate of shoreline erosion, and significant input of freshwaters and sediments from the Colville River, Harrison Bay differs greatly from the other NPR-A estuaries (Naidu et al., 2012). Because it was not sampled, inferences regarding Harrison Bay using data from this survey may be biased (Starcevich et al., 2016).

Recommendations

The use of shallow draft vessels capable of supporting a crew for several days at a time in each estuary should be considered. Improving trawl collections of biota will require increased time, effort, and costs. Difficulties encountered in penetrating the sediment for sampling might be overcome by using a heavier grab sampler with a heavier winch lift capacity, though the hard underlying sediment substrate may be devoid of benthic organisms. A stacked 1.0-mm + 0.5-mm sieve set should be used for macroinvertebrate collection in the shallow NPR-A estuaries; the 0.5-mm sieve improves estimates of diversity and abundance, and the 1.0-mm data allows comparison with past work.

NCCA surveys can provide consistent, large-scale assessments of the spatial extent of the NPR-A ecological condition and inform targeted studies of anthropogenic impacts. Partnerships could be developed with the public, private, federal, and state agency sectors to support continued surveys that, repeated on a five-year cycle, would provide monitoring and early identification of changes in the region.

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Appendix A: Glossary

305(b): Subsection of the Clean Water Act describes reporting for each state's water quality, and is the principal means by which EPA, Congress, and the public evaluate if waters meet water quality standards, monitor maintaining and restoring water quality, and identify problems.

base samples: The number of sites (sample size) that will fulfill the monitoring program requirements for precision and uncertainty (generally, +\- 10% precision at 90% confidence).

condition: The state of a resource, generally reflecting a combination of physical, chemical, and biological characteristics.

ecological indicator: A characteristic of an ecosystem that is related to, or derived from, a measure of a biotic or abiotic attributes that can provide quantitative information on ecological condition, structure and function.

oversamples: Additional sample sites identified in advance for use when a base site cannot be sampled due to frame errors, no access, hazardous site conditions, etc.

probability sample: A probability sample is a sample where every element of the target population has a known, non-zero probability of being selected, and it is possible for every element of the target population to be in the sample. The probability selection mechanism (1) guards against site selection bias and is the basis for scientific inference to characteristics of the entire target population.

reference condition: Set of selected measurements or conditions of unimpaired or minimally impaired waterbodies characteristic of a waterbody type in a region.

sample frame: The list or map that identifies every unit within the target population of interest, a physical representation of the target population. Such a list is needed so that every individual member of the population can be identified unambiguously. The individual members of the target population whose characteristics are to be measured are the sampling units.

sampled population: A conceptual population that is a subset of the intersection of the target population and the sample frame. Sampled population excludes that portion of the target population within the sample frame that could not be sampled due to access problems, lost samples, or other reasons.

status: Often seen as a "snapshot" of resource conditions.

stratum: A subpopulation within which independent probabilistic sampling is conducted.

target population: The aquatic resource about which information is wanted; requires a clear, precise definition of the resource and elements that make up or are associated with the target population (i.e., perennial streams and rivers, lakes or estuaries).

Appendix B: Sampling Design Description and Metadata

Description of Sample Design

The estuary target population included any water body that is tidally influenced, is at least 3-5 PSU, and has less than 50% of its perimeter adjacent to the ocean. The estuary sample frame was created in ArcGIS 10.1 using the best available spatial data as of June 2013 to match the target population definition. Estuaries were mapped by starting with NOAA's Environmental Sensitivity Index (ESI) coastline file for the North Slope (published in 2005, overflights conducted in 1997). The ESI shoreline files were used as the inner boundary for the estuaries and, where barrier islands were present, also as the outer boundary. For estuaries where barrier islands were not present, the estuary outer boundary was closed by connecting the two outermost ends of the inner boundary. The ESI dataset has dangles where shoreline mapping ended along river shorelines. These dangles were connected by drawing a straight line across the river to make a continuous inner boundary for the estuaries. In some inland areas, the ESI dataset ended abruptly along an interior bay or Lake Shoreline. (This may have been due to missing imagery at the time of mapping because the endpoints align vertically along orthophoto tiles). Estuary boundaries were extended in these areas to include the entire inner boundary of the bay or lake. Islands mapped in the ESI dataset and located within the estuaries were erased from the estuary dataset to avoid placing sample points on land. The ESI shoreline mapping was compared to 2010 SPOT satellite orthophotos, which are included in the Statewide Digital Mapping Initiative and accessed through the Alaska Mapped WMS. Due to high rates of annual coastal erosion in the arctic, some shorelines have eroded hundreds of meters from their locations in the ESI dataset. In these areas, estuary boundaries were reshaped to match the 2010 coastline.

Sample frame: The sample frame consists of the ESRI GIS shapefile for NPR-A estuaries. The sample frame has some areas that may not meet the target population definition since salinity data were not available. Salinity measurements must be made at each station in the field potentially with an approximate salinity line being developed if salinities of less than 3 PSU are encountered. In addition, some under coverage may exist due to the rapid rates of coastline erosion in the arctic. The sampling design will include oversample points that can be used when sampling sites accessed in the field do not match the target population definition.

Survey design: A Generalized Random Tessellation Stratified (GRTS) survey design for an area resource was used. The GRTS design includes reverse hierarchical ordering of the selected sites and is stratified with unequal probability of selection based on area within each stratum.

Multi-density categories: Unequal probability category was created based on area of polygons (estuaries) within each stratum.

Stratification: Stratification is based on location being in either a Chukchi or Beaufort estuary stratum.

Expected sample sizes: Chukchi stratum - 20 base stations, with an expected sample size for Kasegaluk Lagoon of 5, Kuk River of 5, and Peard Bay of 10; Beaufort stratum - 20 base stations, with an expected sample for Elson Lagoon of 8, Smith Bay of 6, and Harrison Bay of 6. 40 oversample sites identified for each stratum.

Site use: Base and oversample stations are listed in siteID order for each stratum. All base sites were sampled or reason was documented why that site was not used. Due to limited time within each estuary, if a base station was not sampled the nearest oversample station was utilized.

Table B.1. Sample frame summary (total estuarine area 2970.77 km^2).

Estuary Area		Base Sites	Oversample Sites	Total Area (km^2)
Chukchi Stratum				
	Kasegaluk Lagoon	5		231.30
	Wainwright Inlet	5		269.67
	Peard	10		324.65
Total		*20*	*40*	*825.61*
Beaufort Stratum				
	Elson Lagoon	8		1079.61
	Smith Bay	6		364.37
	Harrison Bay	6		701.18
Total		*20*	*40*	*2145.16*

Description of Sample Design Output

The sites are provided as a ESRI ArcGIS shapefile that can be read directly by ArcMap, which can be read by Excel. It is also provided in an Excel file workbook format.

Table B.2. Variable definitions.

Variable Name	**Description**
Shapefile Dbf file variable definitions:	
SiteID	Unique site identification (character)
Arcid	Internal identification number
X	Albers x-coordinate
Y	Albers y-coordinate
Mdcaty	Multi-density categories used for unequal probability selection
Weight	Weighting (in meters), inverse of inclusion probability, used in statistical analyses
Stratum	Strata used in the survey design
Panel	Identifies base sample by panel name and Oversample by OverSamp
auxiliary variables	Remaining columns are from the sample frame provided
Variable Name	Description
Excel file variable definitions:	
SiteID	Unique site identification (character)
Arcid	Internal identification number
X	Albers x-coordinate
Y	Albers y-coordinate
Mdcaty	Multi-density categories used for unequal probability selection
Weight	Weighting (in meters), inverse of inclusion probability, used in statistical analyses
Stratum	Strata used in the survey design
Panel	Identifies base sample by panel name and Oversample by OverSamp
Auxiliary variables	Remaining columns are from the sample frame provided
LatDD	Station latitude in decimal degrees. Datum NAD 83 see projection information.
LongDD	Station longitude in decimal degrees. Datum NAD 83 see projection information.

Evaluation Process

The survey design weights that are given in the design file assume that the survey design is implemented as designed. That is, only the sites that are in the base sample (not in the oversample) are used, and all of the base sites are used. If base stations cannot be sampled, oversample sites can be used to achieve the sample size planned. However, as a general rule, when oversample sites are used, the survey design weights are no longer correct and must be adjusted during the data analysis. The weight adjustment requires knowing what happened to each site in the base design and the oversample sites. EvalStatus is initially set to “NotEval” to indicate that the site has yet to be evaluated for sampling. When a site is evaluated for sampling, then the EvalStatus for the site must be changed using codes in Table A.3.

Table B.3. Evaluation status and NCCA codes.

EvalStatus or NCCA Code	*Name*	*Meaning*
TS	Target Sampled	Site is a member of the target population and was sampled.
TNS	Target Not Sampled	Base or oversample station evaluated but not sampled due to shallow depth.
T_O	Target Other	Used for Harrison Bay targeted sites that could not be sampled
NE	Not evaluated	
PB	Physical Barrier	Physical barrier prevented access to the site i.e., sand bar or station to shallow.
O	Other	Field team provides description of why it was not possible to sample the station.

Table B.4. NPR-A 2015 design base and oversample station locations.[1]

Design_ID	mdcaty	Orig_wgt	Corr_wgt	Region	stratum	panel	Estuary_Name	Dsg_LatDD	Dsg_LongDD	Field_LatDD	Field_LongDD
NPRA2015-001	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.7127	-159.227	NA	NA
NPRA2015-002	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.8612	-159.1933	NA	NA
NPRA2015-003	Kuk	44.94418	33.708125	NPRA	Chukchi	Base	Wainwright Inlet	70.3686	-159.9723	NA	NA
NPRA2015-004	Kasegaluk	46.25914	28.912	NPRA	Chukchi	Base	Kasegaluk Lagoon	70.3748	-160.7504	NA	NA
NPRA2015-005	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.7969	-158.8177	70.79668	-158.81764
NPRA2015-006	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.8916	-158.8069	NA	NA
NPRA2015-007	Kuk	44.94418	33.708125	NPRA	Chukchi	Base	Wainwright Inlet	70.3482	-160.0403	NA	NA
NPRA2015-008	Kasegaluk	46.25914	28.912	NPRA	Chukchi	Base	Kasegaluk Lagoon	70.4075	-160.666	NA	NA
NPRA2015-009	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.7763	-159.1597	70.77606	-159.16023
NPRA2015-010	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.838	-158.7635	70.83772	-158.76328
NPRA2015-011	Kuk	44.94418	33.708125	NPRA	Chukchi	Base	Wainwright Inlet	70.5106	-159.7767	70.51008	-159.7809
NPRA2015-012	Kasegaluk	46.25914	28.912	NPRA	Chukchi	Base	Kasegaluk Lagoon	70.2785	-161.7656	NA	NA
NPRA2015-013	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.8271	-158.5642	70.82645	-158.56464
NPRA2015-014	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.7637	-159.3496	NA	NA
NPRA2015-015	Kuk	44.94418	33.708125	NPRA	Chukchi	Base	Wainwright Inlet	70.6002	-159.9868	70.6001	-159.9874
NPRA2015-016	Kasegaluk	46.25914	28.912	NPRA	Chukchi	Base	Kasegaluk Lagoon	70.2929	-161.6503	70.29276	-161.64851
NPRA2015-017	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.772	-159.0287	NA	NA
NPRA2015-018	Peard	36.07207	21.64326667	NPRA	Chukchi	Base	Peard Bay & Kugra Bay	70.853	-158.9497	70.85295	-158.95015
NPRA2015-019	Kuk	44.94418	33.708125	NPRA	Chukchi	Base	Wainwright Inlet	70.4669	-160.0872	NA	NA
NPRA2015-020	Kasegaluk	46.25914	28.912	NPRA	Chukchi	Base	Kasegaluk Lagoon	70.3016	-161.665	NA	NA
NPRA2015-061	Smith	72.87483	36.4374	NPRA	Beaufort	Base	Smith Bay	70.8282	-154.488	NA	NA
NPRA2015-062	Smith	72.87483	36.4374	NPRA	Beaufort	Base	Smith Bay	70.8507	-154.4163	NA	NA
NPRA2015-063	Elson	134.9516	89.96775	NPRA	Beaufort	Base	Elson Lagoon, Admiralty, Ikon, and Fatigue Bay	70.9097	-155.6087	NA	NA
NPRA2015-064	Harrison	100.16849	35.05895	NPRA	Beaufort	Base	Harrison Bay	70.5274	-151.7165	NA	NA
NPRA2015-065	Elson	134.9516	89.96775	NPRA	Beaufort	Base	Elson Lagoon, Admiralty, Ikon, and Fatigue Bay	71.3674	-156.4661	71.36658	-156.46556
NPRA2015-066	Smith	72.87483	36.4374	NPRA	Beaufort	Base	Smith Bay	70.9055	-154.5254	70.90526	-154.52477
NPRA2015-067	Elson	134.9516	89.96775	NPRA	Beaufort	Base	Elson Lagoon, Admiralty, Ikon, and Fatigue Bay	71.2046	-155.8126	71.20421	-155.81281
NPRA2015-068	Harrison	100.16849	35.05895	NPRA	Beaufort	Base	Harrison Bay	70.6188	-151.8344	NA	NA
NPRA2015-069	Elson	134.9516	89.96775	NPRA	Beaufort	Base	Elson Lagoon, Admiralty, Ikon, and Fatigue Bay	71.1266	-155.5367	71.12628	-155.53656
NPRA2015-070	Elson	134.9516	89.96775	NPRA	Beaufort	Base	Elson Lagoon, Admiralty, Ikon, and Fatigue Bay	70.9727	-155.5638	NA	NA
NPRA2015-071	Smith	72.87483	36.4374	NPRA	Beaufort	Base	Smith Bay	70.8888	-153.9899	NA	NA
NPRA2015-072	Harrison	100.16849	35.05895	NPRA	Beaufort	Base	Harrison Bay	70.6015	-152.0639	NA	NA
NPRA2015-073	Smith	72.87483	36.4374	NPRA	Beaufort	Base	Smith Bay	70.8654	-154.2519	70.86619	-154.25139
NPRA2015-074	Elson	134.9516	89.96775	NPRA	Beaufort	Base	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	70.9688	-155.7599	NA	NA
NPRA2015-075	Harrison	100.16849	35.05895	NPRA	Beaufort	Base	Harrison Bay	70.4125	-151.2936	NA	NA
NPRA2015-076	Harrison	100.16849	35.05895	NPRA	Beaufort	Base	Harrison Bay	70.6824	-152.0998	NA	NA
NPRA2015-077	Elson	134.9516	89.96775	NPRA	Beaufort	Base	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.1252	-155.2296	NA	NA
NPRA2015-078	Smith	72.87483	36.4374	NPRA	Beaufort	Base	Smith Bay	70.9019	-154.5986	NA	NA
NPRA2015-079	Elson	134.9516	89.96775	NPRA	Beaufort	Base	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.2774	-156.0183	71.27721	-156.01894
NPRA2015-080	Harrison	100.16849	35.05895	NPRA	Beaufort	Base	Harrison Bay	70.7252	-152.3466	NA	NA
NPRA2015-024	Kasegaluk	46.25914	28.912	NPRA	Chukchi	OverSamp	Kasegaluk Lagoon	70.2879	-161.3814	70.28793	-161.38142
NPRA2015-025	Peard	36.07207	21.64326667	NPRA	Chukchi	OverSamp	Peard Bay & Kugra Bay	70.8169	-158.6548	70.81623	-158.65599
NPRA2015-028	Kasegaluk	46.25914	28.912	NPRA	Chukchi	OverSamp	Kasegaluk Lagoon	70.2657	-161.5276	70.26575	-161.52661
NPRA2015-033	Peard	36.07207	21.64326667	NPRA	Chukchi	OverSamp	Peard Bay & Kugra Bay	70.796	-159.1695	70.79699	-159.16907
NPRA2015-037	Peard	36.07207	21.64326667	NPRA	Chukchi	OverSamp	Peard Bay & Kugra Bay	70.7956	-158.6168	70.79523	-158.61818
NPRA2015-039	Kuk	44.94418	33.708125	NPRA	Chukchi	OverSamp	Wainwright Inlet	70.4654	-159.8306	70.46702	-159.82925
NPRA2015-044	Kasegaluk	46.25914	28.912	NPRA	Chukchi	OverSamp	Kasegaluk Lagoon	70.2664	-161.5008	70.26598	-161.49812
NPRA2015-047	Kuk	44.94418	33.708125	NPRA	Chukchi	OverSamp	Wainwright Inlet	70.4451	-159.8855	70.44557	-159.8809
NPRA2015-049	Peard	36.07207	21.64326667	NPRA	Chukchi	OverSamp	Peard Bay & Kugra Bay	70.7916	-159.2122	70.79145	-159.2127
NPRA2015-050	Peard	36.07207	21.64326667	NPRA	Chukchi	OverSamp	Peard Bay & Kugra Bay	70.8761	-158.8704	70.87621	-158.87074
NPRA2015-051	Kuk	44.94418	33.708125	NPRA	Chukchi	OverSamp	Wainwright Inlet	70.5541	-159.8708	70.55376	-159.8718
NPRA2015-082	Elson	134.9516	89.96775	NPRA	Beaufort	OverSamp	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.0366	-155.5945	71.0373	-155.5879
NPRA2015-084	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.6373	-152.07	NA	NA
NPRA2015-087	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.4496	-151.2471	NA	NA
NPRA2015-088	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.7688	-152.1552	NA	NA
NPRA2015-092	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.4771	-151.817	NA	NA
NPRA2015-095	Elson	134.9516	89.96775	NPRA	Beaufort	OverSamp	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.3082	-156.25	71.30807	-156.25009
NPRA2015-096	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.6486	-152.4113	NA	NA
NPRA2015-099	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.553	-152.3393	NA	NA
NPRA2015-100	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.638	-151.9318	NA	NA
NPRA2015-101	Smith	72.87483	36.4374	NPRA	Beaufort	OverSamp	Smith Bay	70.9116	-154.1336	NA	NA
NPRA2015-103	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.455	-151.5013	NA	NA
NPRA2015-104	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.7066	-152.0934	NA	NA
NPRA2015-106	Smith	72.87483	36.4374	NPRA	Beaufort	OverSamp	Smith Bay	70.8965	-154.5157	70.89648	-154.51714
NPRA2015-107	Elson	134.9516	89.96775	NPRA	Beaufort	OverSamp	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.2981	-155.9914	71.29836	-155.99196
NPRA2015-108	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.5144	-151.7662	NA	NA
NPRA2015-112	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.6241	-152.393	NA	NA
NPRA2015-113	Smith	72.87483	36.4374	NPRA	Beaufort	OverSamp	Smith Bay	70.9095	-154.4704	70.90934	-154.47159
NPRA2015-114	Elson	134.9516	89.96775	NPRA	Beaufort	OverSamp	Elson Lagoon, Admiralty, Ikon, and Fatigue Bay	71.3265	-156.4311	71.32653	-156.42862
NPRA2015-115	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.5584	-152.065	NA	NA
NPRA2015-116	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.6158	-152.1914	NA	NA
NPRA2015-119	Harrison	100.16849	35.05895	NPRA	Beaufort	OverSamp	Harrison Bay	70.4986	-151.6234	NA	NA
NPRA2015-120	Smith	72.87483	36.4374	NPRA	Beaufort	OverSamp	Smith Bay	70.819	-154.0726	70.8197	-154.07578

[1] Original design had reversed the estuary sizes for Harrison and Smith Bay necessitating a correction to the based and oversample design weights.

Table B.4. Sampled station coordinates

Station	Estuary	Dsg_LatDD	Dsg_LongDD	Act_LatDD	Act_LongDD
AK-NCCA15-005	Peard Bay & Kugra Bay	70.79690	-158.81770	70.79668	-158.81764
AK-NCCA15-009	Peard Bay & Kugra Bay	70.77630	-159.15970	70.77606	-159.16023
AK-NCCA15-010	Peard Bay & Kugra Bay	70.83800	-158.76350	70.83772	-158.76328
AK-NCCA15-011	Wainwright Inlet	70.51060	-159.77670	70.51008	-159.78090
AK-NCCA15-013	Peard Bay & Kugra Bay	70.82710	-158.56420	70.82645	-158.56464
AK-NCCA15-015	Wainwright Inlet	70.60020	-159.98680	70.60010	-159.98740
AK-NCCA15-016	Kasegaluk Lagoon	70.29290	-161.65030	70.29276	-161.64851
AK-NCCA15-018	Peard Bay & Kugra Bay	70.85300	-158.94970	70.85295	-158.95015
AK-NCCA15-065	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.36740	-156.46610	71.36658	-156.46556
AK-NCCA15-066	Smith Bay	70.90550	-154.52540	70.90526	-154.52477
AK-NCCA15-067	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.20460	-155.81260	71.20421	-155.81281
AK-NCCA15-069	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.12660	-155.53670	71.12628	-155.53656
AK-NCCA15-073	Smith Bay	70.86540	-154.25190	70.86619	-154.25139
AK-NCCA15-079	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.27740	-156.01830	71.27721	-156.01894
AK-NCCA15-024	Kasegaluk Lagoon	70.28790	-161.38140	70.28793	-161.38142
AK-NCCA15-025	Peard Bay & Kugra Bay	70.81690	-158.65480	70.81623	-158.65599
AK-NCCA15-028	Kasegaluk Lagoon	70.26570	-161.52760	70.26575	-161.52661
AK-NCCA15-033	Peard Bay & Kugra Bay	70.79600	-159.16950	70.79699	-159.16907
AK-NCCA15-037	Peard Bay & Kugra Bay	70.79560	-158.61680	70.79523	-158.61818
AK-NCCA15-039	Wainwright Inlet	70.46540	-159.83060	70.46702	-159.82925
AK-NCCA15-044	Kasegaluk Lagoon	70.26640	-161.50080	70.26598	-161.49812
AK-NCCA15-047	Wainwright Inlet	70.44510	-159.88550	70.44557	-159.88090
AK-NCCA15-049	Peard Bay & Kugra Bay	70.79160	-159.21220	70.79145	-159.21269
AK-NCCA15-050	Peard Bay & Kugra Bay	70.87610	-158.87040	70.87621	-158.87074
AK-NCCA15-051	Wainwright Inlet	70.55410	-159.87080	70.55376	-159.87180
AK-NCCA15-082	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.03660	-155.59450	71.03730	-155.58790
AK-NCCA15-095	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.30820	-156.25000	71.30807	-156.25009
AK-NCCA15-106	Smith Bay	70.89650	-154.51570	70.89648	-154.51714
AK-NCCA15-107	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.29810	-155.99140	71.29836	-155.99196
AK-NCCA15-113	Smith Bay	70.90950	-154.47040	70.90934	-154.47159
AK-NCCA15-114	Elson Lagoon, Admiralty, Ikon, Fatigue Bay	71.32650	-156.43110	71.32653	-156.42862
AK-NCCA15-120	Smith Bay	70.81900	-154.07260	70.81970	-154.07578
AK-NCCA-15-D1B	Wainwright Offshore Deep	70.70970	-160.01940	70.70970	-160.01940
AK-NCCA-15-D2B	Wainwright Offshore Deep	70.71285	-159.97253	70.71285	-159.97253
AK-NCCA-15-D3B	Wainwright Offshore Deep	70.74202	-159.86392	70.74202	-159.86392
AK-NCCA-15-D5B	Wainwright Offshore Deep	70.79037	-159.75317	70.79037	-159.75317
AK-NCCA-15-S10B	Wainwright Offshore Shallow	70.79037	-159.70834	70.77530	-159.70834
AK-NCCA-15-S9B	Wainwright Offshore Shallow	70.75813	-159.75840	70.75813	-159.75840
Datum: NAD83					

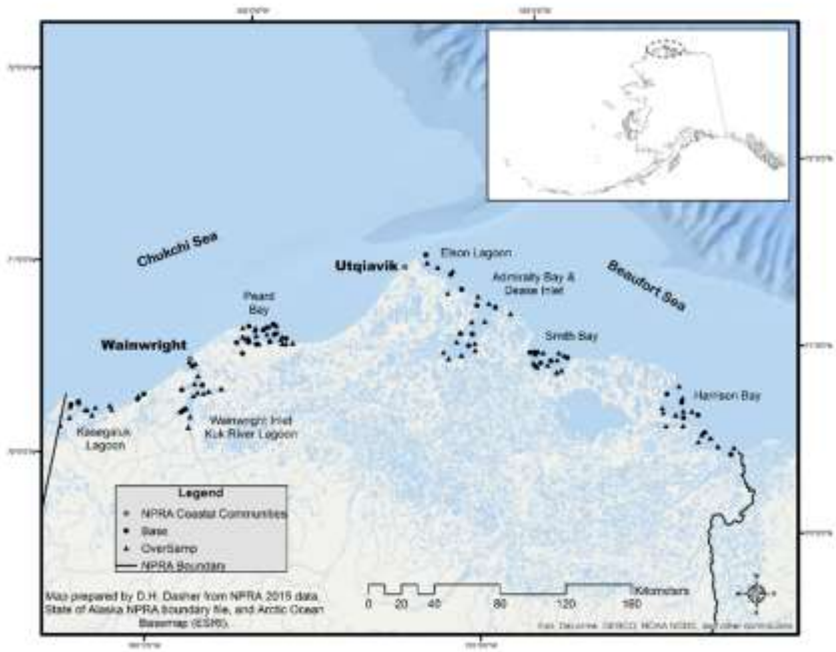


Figure B.1. NPR-A Estuary base and oversample stations.

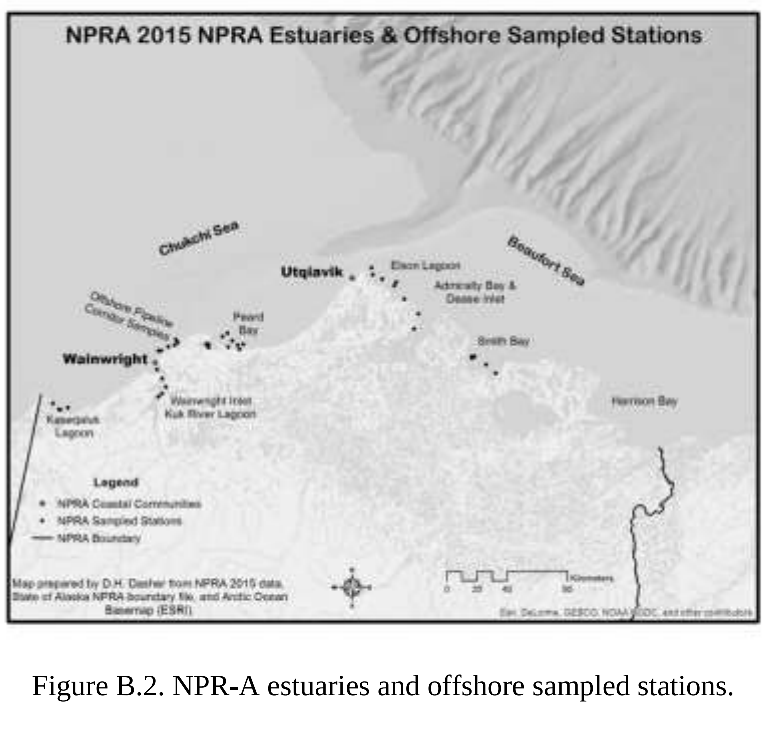


Figure B.2. NPR-A estuaries and offshore sampled stations.

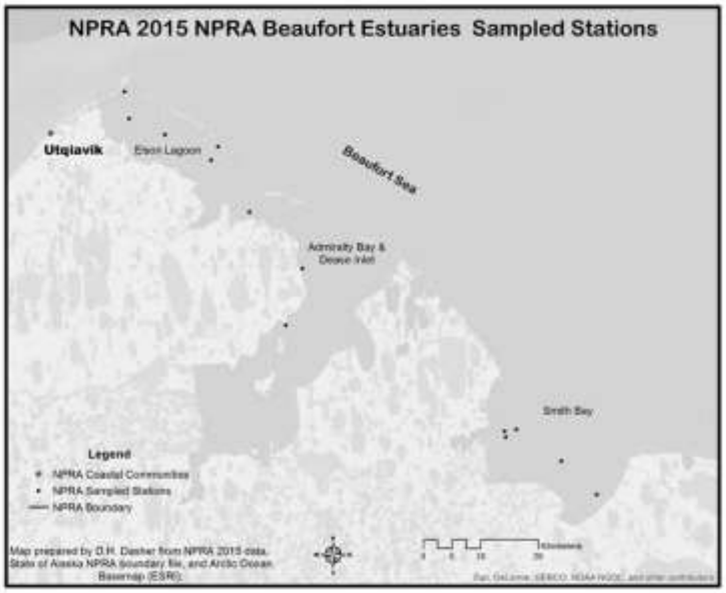


Figure B.3. NPR-A estuaries Beaufort sampled stations.

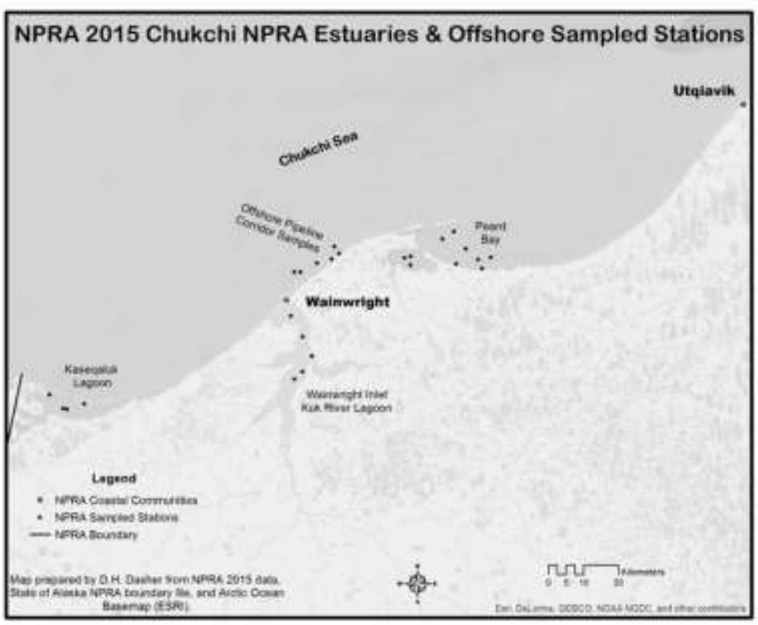


Figure B.4. NPR-A Chukchi estuaries and offshore sampled stations.

Appendix C: Analyte Lists

Table C.1.Water quality measurements.

Nutrients	Lab[4]	CTD	Other	Lab
Filtered < 45 µm & Unfiltered	A	Pressure/Depth	Total Suspended Solids	B
Ammonia NH3-N	A	Temperature	Secchi Disk	A
Nitrate NO3-N	A	PSU	Chlorophyll *a*	C
Phosphorus PO4	A	Dissolved Oxygen & PAR		

Table C.1 - Other Analytical and Taxonomic Work

Sediment			Lab	Biological	Lab
Total Carbon, Organic & Inorganic			E, F	Sediment macroinvertebrates 1mm & 0.5mm sieve	E
Grain Size			B	Beam Trawl – Taxonomic identifications	E
Carbon/Nitrogen Stable Isotopes			E	% Lipids for fish tissues	F

Table C.3. PAH and individual alkyl isomers, TAS and hopanes.

PAH	Individual Alkyl Isomers, TAS, and hopanes
cis/trans Decalin	2-Methylnaphthalene
Naphthalene	1-Methylnaphthalene
Benzothiophene	2,6-Dimethylnaphthalene
Biphenyl	1,6,7-Trimethylnaphthalene
Acenaphthylene	1-Methylfluorene
Acenaphthene	4-Methyldibenzothiophene
Dibenzofuran	2/3-Methyldibenzothiophene
Fluorene	1-Methyldibenzothiophene
Carbazole	3-Methylphenanthrene
Anthracene	2/4-Methylphenanthrene
Phenanthrene	2-Methylanthracene
Dibenzothiophene	9-Methylphenanthrene
Fluoranthene	1-Methylphenanthrene
Pyrene	3,6-Dimethylphenanthrene
Naphthobenzothiophene	Retene
Benz(a)anthracene	2-Methylfluoranthene
Chrysene/Triphenylene	Benzo(b)fluorene
Benzo(b)fluoranthene	C29-Hopane
Benzo(k,j)fluoranthene	18a-Oleanane
Benzo(a)fluoranthene	C30-Hopane
Benzo(e)pyrene	C20-TAS
Benzo(a)pyrene	C21-TAS
Perylene	C26(20S)-TAS
Indeno(1,2,3-c,d)pyrene	C26(20R)/C27(20S)-TAS
Dibenzo(a,h)anthracene	C28(20S)-TAS
Benzo(g,h,i)perylene	C27(20R)-TAS
	C28(20R)-TAS

[4] A – NOAA PMEL, B – UAF IMS AKMAP Lab, C- UAF IMS/ Dean Stockwell, D-UAF Stable Isotope Lab, E- UAF IMS Taxonomic Lab, F - TDI

Table C.4. Alkylated PAHs.

C1-Decalins C2-Decalins	**C2-Dibenzothiophenes**
C2-Decalins	C3-Dibenzothiophenes
C3-Decalins	C4-Dibenzothiophenes
C4-Decalins	C1-Fluoranthenes/Pyrenes
C1-Naphthalenes	C2-Fluoranthenes/Pyrenes
C2-Naphthalenes	C3-Fluoranthenes/Pyrenes
C3-Naphthalenes	C4-Fluoranthenes/Pyrenes
C4-Naphthalenes	C1-Naphthobenzothiophenes
C1-Fluorenes	C2-Naphthobenzothiophenes
C2-Fluorenes	C4-Fluoranthenes/Pyrenes
C3-Fluorenes	C3-Naphthobenzothiophenes
C1-Phenanthrenes/Anthracenes	C4-Naphthobenzothiophenes
C2-Phenanthrenes/Anthracenes	C1-Chrysenes
C3-Phenanthrenes/Anthracenes	C2-Chrysenes
C4-Phenanthrenes/Anthracenes	C3-Chrysenes
C1-Dibenzothiophenes	C4-Chrysenes

Table C.2 n-alkanes.

n-Alkanes	
n-C9	n-C25
n-C10	n-C26
n-C11	n-C27
n-C12	n-C28
n-C13	n-C29
i-c15	n-C30
n-C14	n-C31
i-c16	n-C32
n-C15	n-C33
n-C16	n-C34
i-c18	n-C35
n-C17	n-C36
Pristane	n-C37
n-C18	n-C38
Phytane	n-C39
n-C19	n-C40
n-C20	
n-C21	Total Petroleum Hydrocarbons
n-C22	Total Resolved Hydrocarbons
n-C23	Unresolved Complex Mixture
n-C24	Extractable Organic Matter

Table C.3 - Saturated biomarkers.

C23 Tricyclic Terpane	T22a-Gammacerane/C32-diahopane
C24 Tricyclic Terpane	30,31-Bishomohopane-22S
C25 Tricyclic Terpane	30,31-Bishomohopane-22R
C24 Tetracyclic Terpane	30,31-Trishomohopane-22S
C26 Tricyclic Terpane-22S	30,31-Trishomohopane-22R
C26 Tricyclic Terpane-22R	Tetrakishomohopane-22S
C28 Tricyclic Terpane-22S	Tetrakishomohopane-22R
C28 Tricyclic Terpane-22R	Pentakishomohopane-22S
C29 Tricyclic Terpane-22S	Pentakishomohopane-22R
C29 Tricyclic Terpane-22R	13b(H),17a(H)-20S-Diacholestane
18a-22,29,30-Trisnorneohopane-Ts	13b(H),17a(H)-20R-Diacholestane
17a(H)-22,29,30-Trisnorhopane-Tm	13b,17a-20S-Methyldiacholestane
C30-Tricyclic Terpane-22S	14a(H),17a(H)-20S-Cholestane
C30-Tricyclic Terpane-22R	14b(H),17b(H)-20R-Cholestane
17a/b,21b/a 28.30-Bisnorhopane	14b(H),17b(H)-20S-Cholestane
17a(H),21b(H)-25-Norhopane	14a(H),17a(H)-20R-Cholestane
30-Norhopane	13b,17a-20R-Ethyldiacholestane
18a(H)-30-Norneohopane-C29Ts	13a,17b-20S-Ethyldiacholestane
17a(H)-Diahopane	14a,17a-20S-Methylcholestane
30-Normoretane	14b,17b-20R-Methylcholestane
18a(H)&18b(H)-Oleananes	14b,17b-20S-Methylcholestane
Hopane	14a,17a-20R-Methylcholestane
Moretane	14a(H),17a(H)-20S-Ethylcholestane
30-Homohopane-22S	14b(H),17b(H)-20R-Ethylcholestane
30-Homohopane-22R	14b(H),17b(H)-20S-Ethylcholestane
14a(H),17a(H)-20R-Ethylcholestane	

Appendix D: Cumulative Distribution Function Graphs for Select Water/Sediment Quality Measures

Interpretation of NPR-A estuary survey Cumulative Distribution Functions (CDF)

Based on the survey design, the condition and indicator results represent the target population (or in our case the sampled population), and results relative to the cumulative percentage of the areas estuary and near shore area surveyed are used in the ranking by region process. Calculations of CDFs provide the proportion (cumulative percentage area) of the study area that is above or below some threshold or indicator value (e.g. water quality standards). For example, Figure D.1 represents a CDF of bottom dissolved oxygen (DO) measurements taken across the NPR-A sample population. The X axis provides the estimated DO mg/L and the Y axis represents the cumulative percentage of the area surveyed. The solid black line, Estimate P, represents the estimate of cumulative percentage area and its corresponding DO mg/L level. The dotted lines LCB95Pct.P (red) and UCB95Pct.P (blue) show the upper and lower 95% confidence limits. The median or 50% value line (highlighted in blue) indicates that 50% of the cumulative area targeted had a DO less than or equal to ~ 13.0 mg/L (with upper and lower 95% confidence levels of ~ 12.80 and ~ 13.20 mg/L, respectively). Based on this data, NPR-A surveyed estuaries do not have bottom dissolved oxygen concentrations lower than 4 mg/L or above 17 mg/L, the limits set in the State of Alaska's Water Quality Standards.

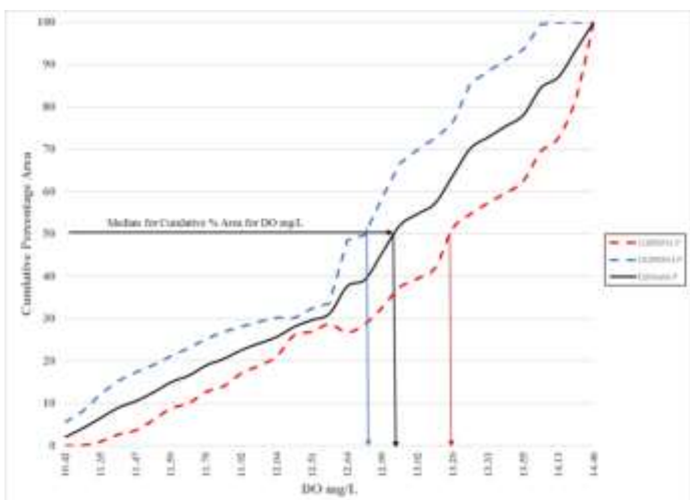


Figure D.1. Example NPR-A DO mg/L CDF.

The following figures (D.2-D.13) present NPR-A and Beaufort and Chukchi strata water column CDF's for early- to mid-August conditions and include surface temperature, pH, PSU, DO, CTD binned values for ~ 1M depth, and water samples for TSS, nutrients and chlorophyll *a* ~ 0.5 M depth.

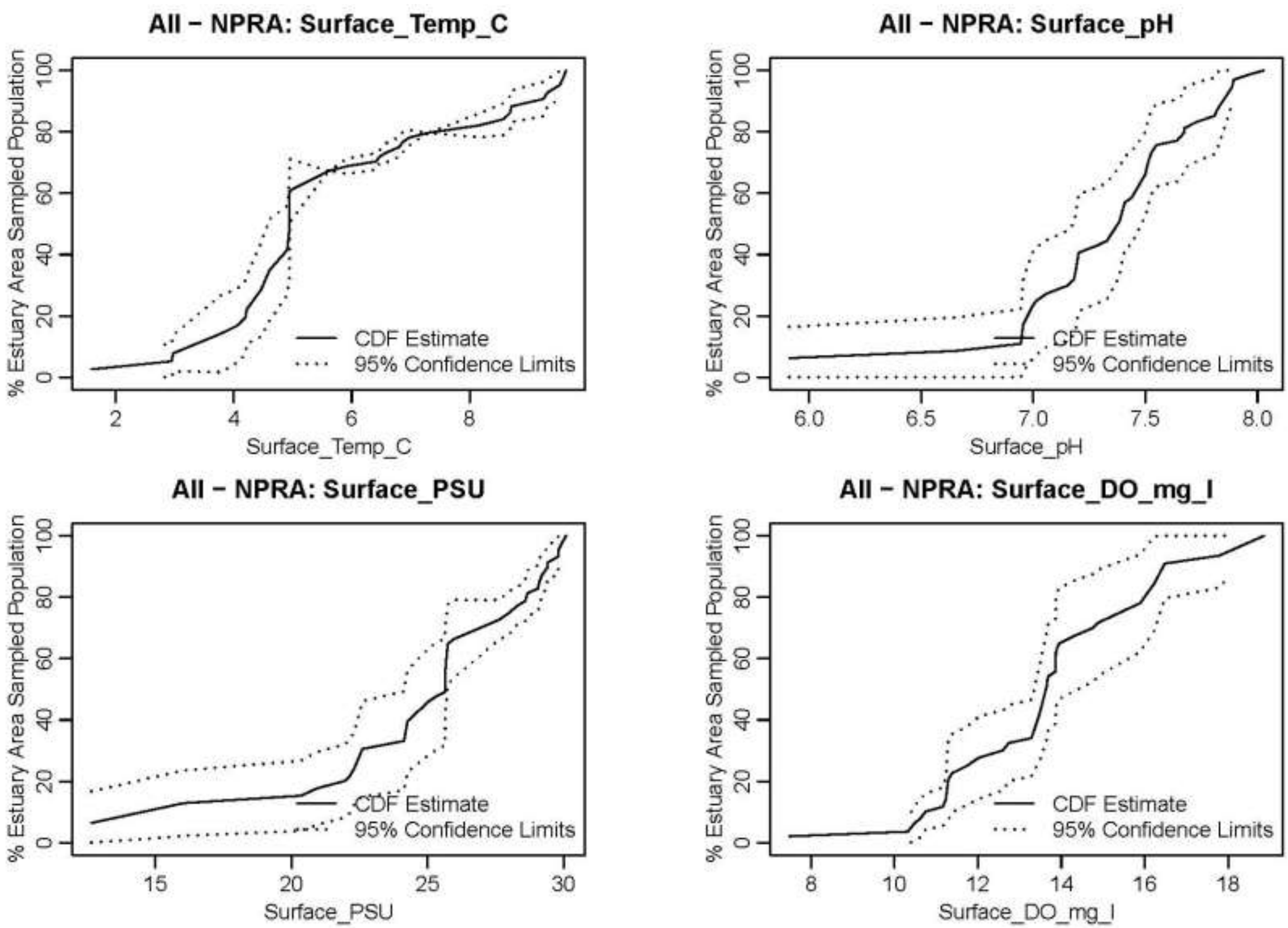


Figure D.2. All NPR-A surface temperature ^{o}C, pH, PSU, and DO mg/L.

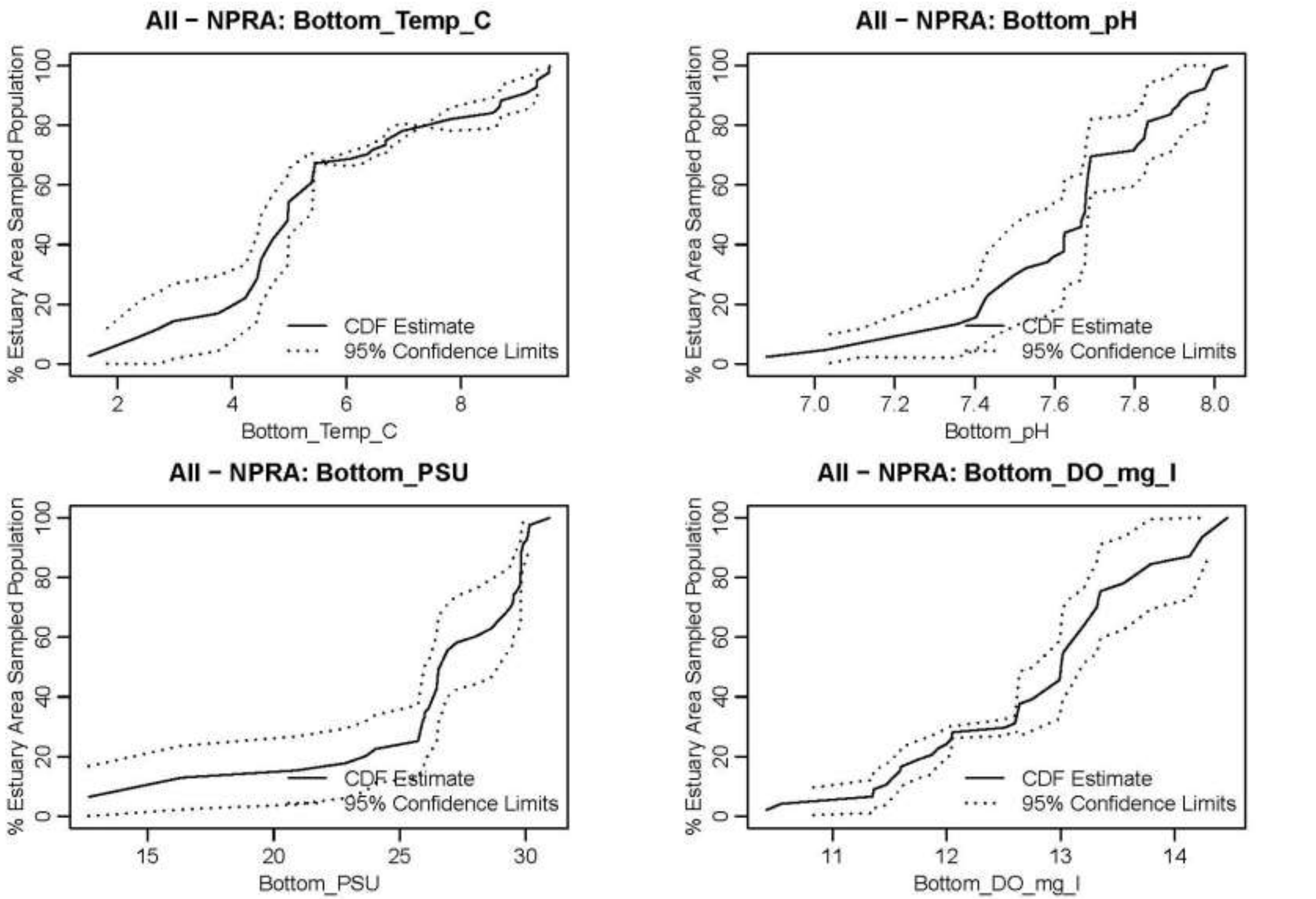


Figure D.3. All NPR-A bottom temperature ^{o}C, pH, PSU, and DO mg/L

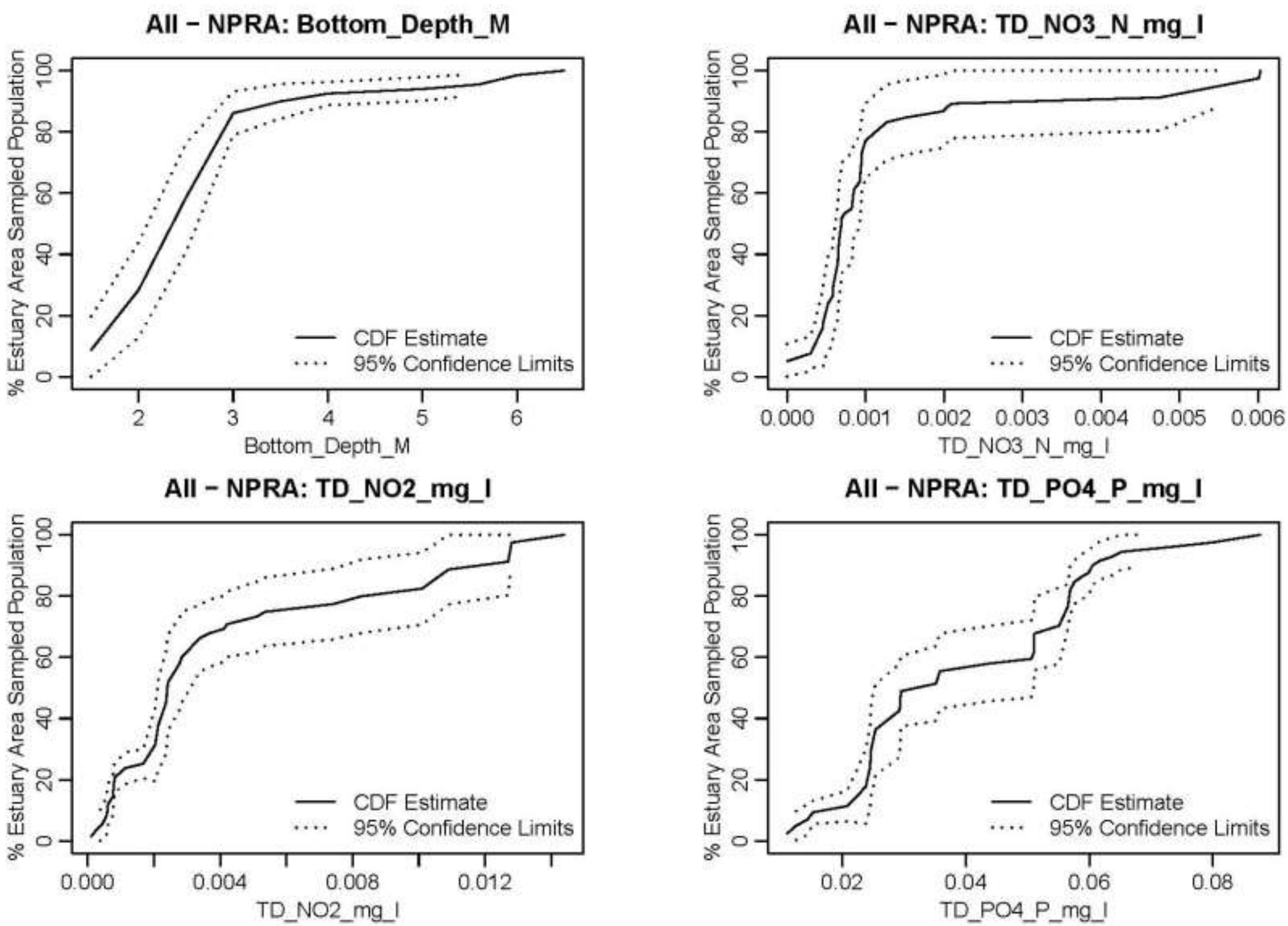


Figure D.4. All NPR-A station bottom depth M, and ~ 1 meter depth TD NO_3 as N, NO_2, and PO_4 as P mg/L

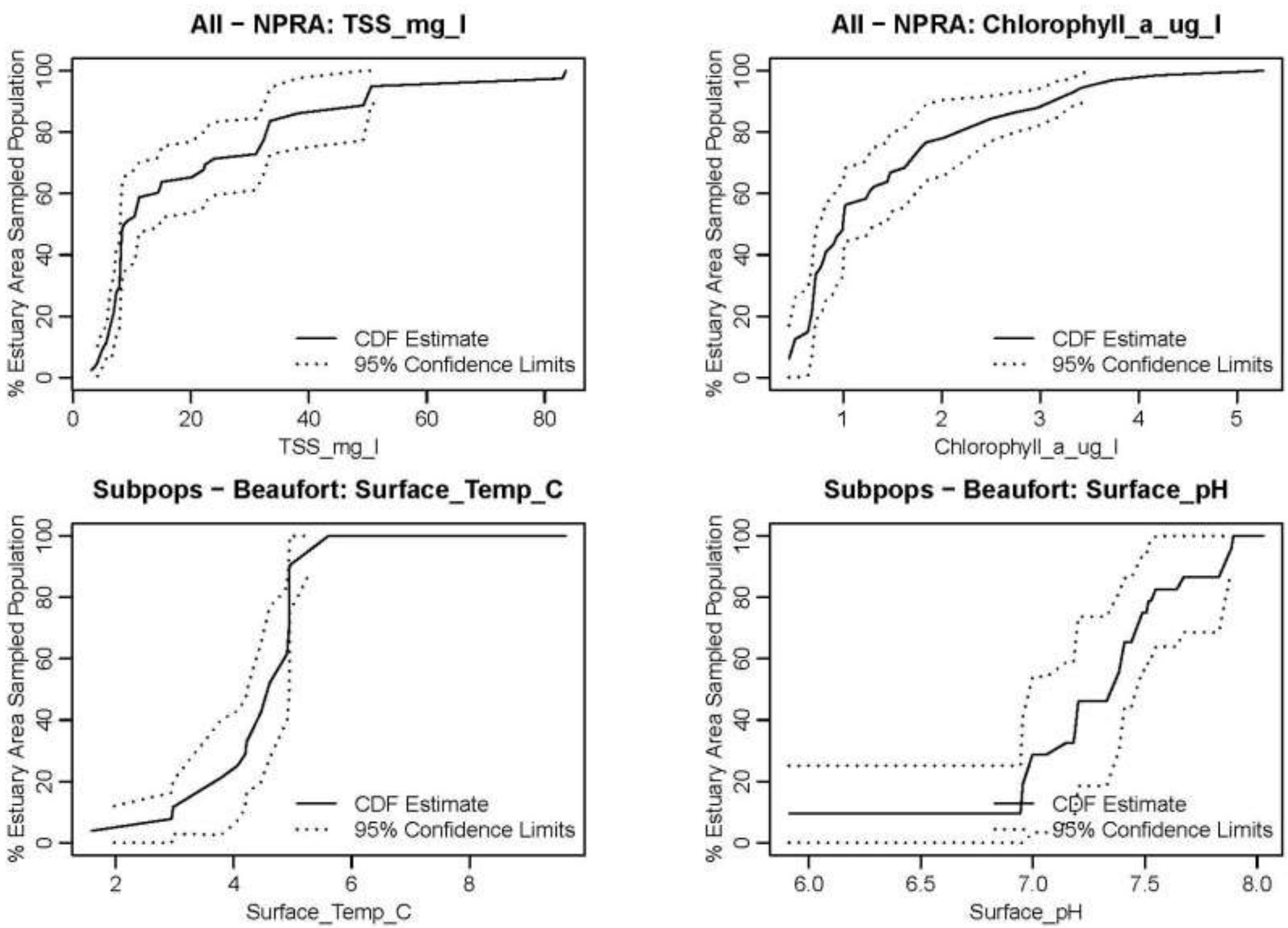


Figure D.5. All NPR-A ~ 1 meter depth TSS mg/L and Chlorophyll *a* ug/L; NPR-A Beaufort stratum surface temperature ^{o}C and pH.

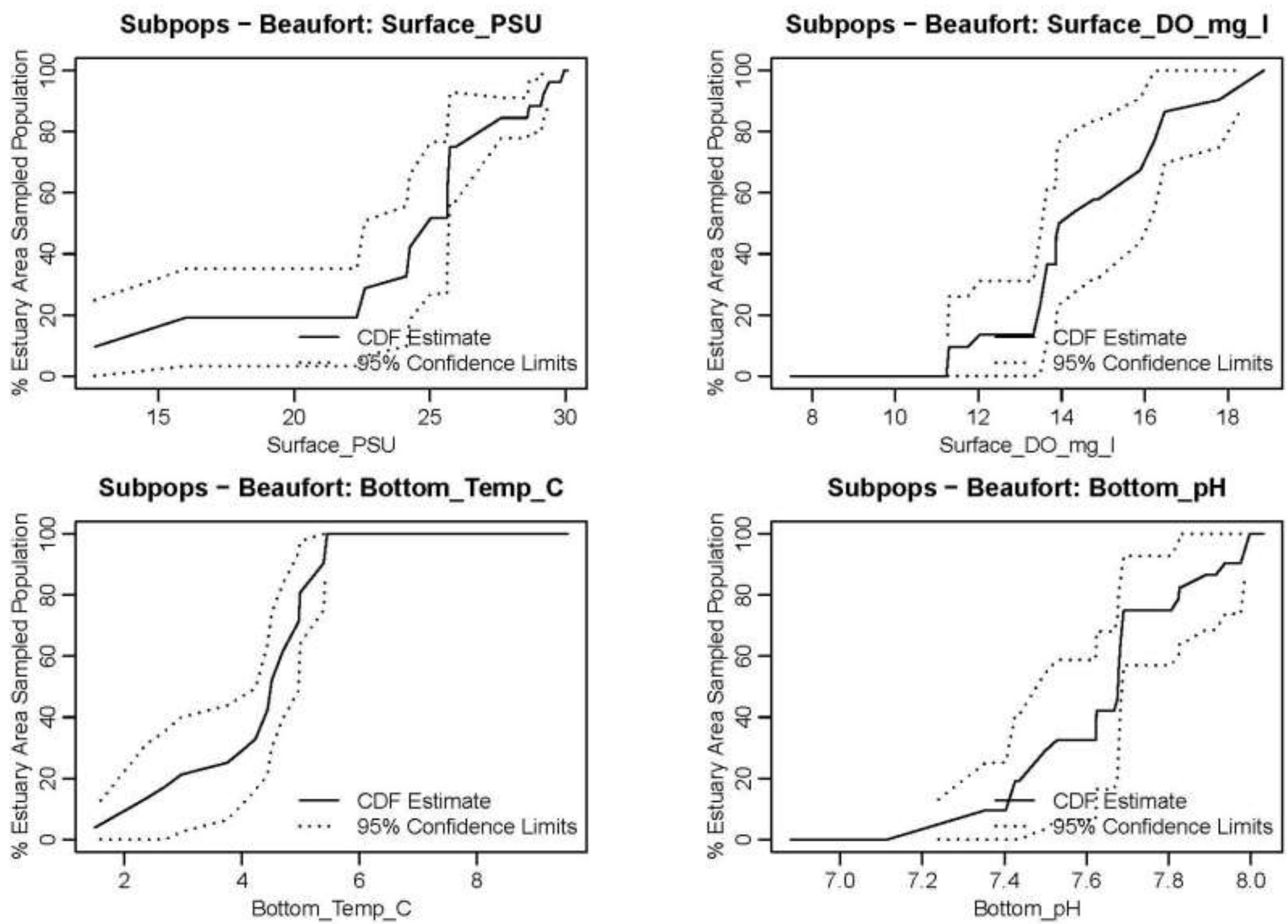
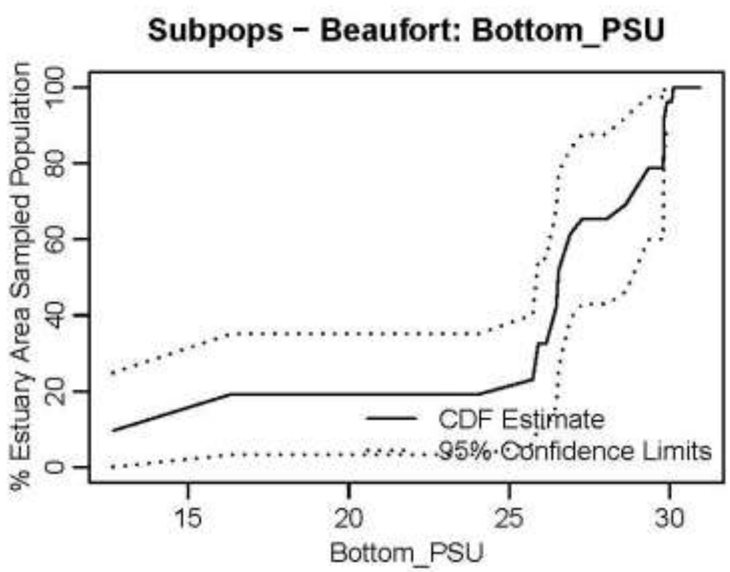
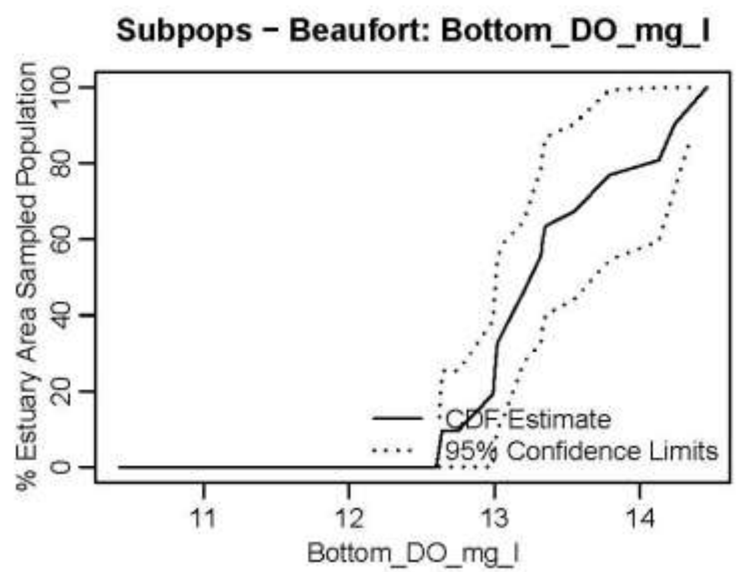
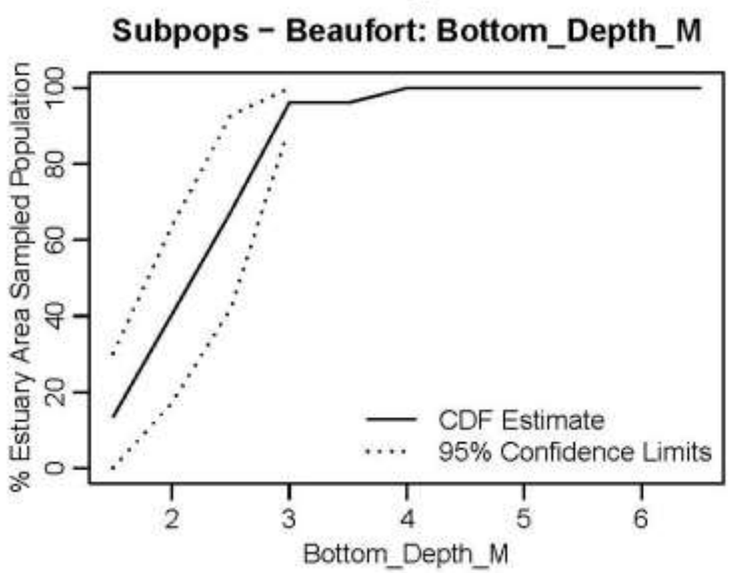


Figure D.1 – NPR-A Beaufort Stratum Surface PSU, DO mg/L and bottom temperature ^{o}C, and pH.







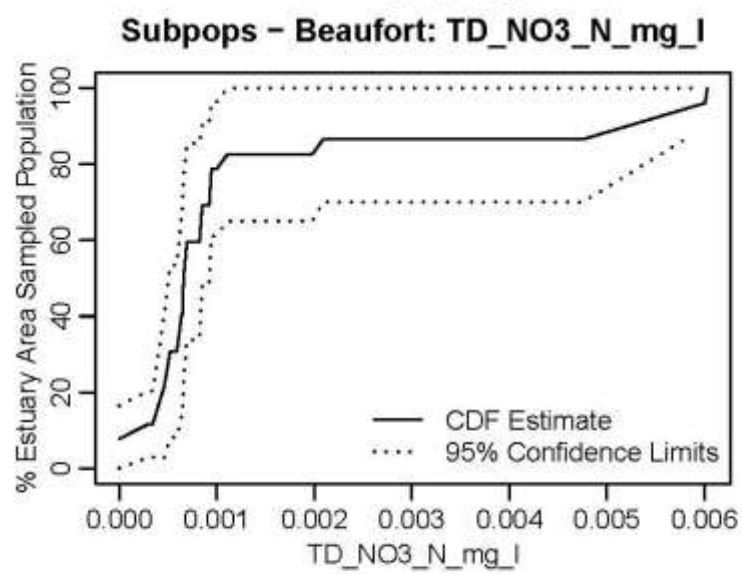


Figure D.7. NPR-A Beaufort stratum PSU, DO mg/L, bottom depth M, and ~ 1 meter depth TD NO^3 as N mg/L.

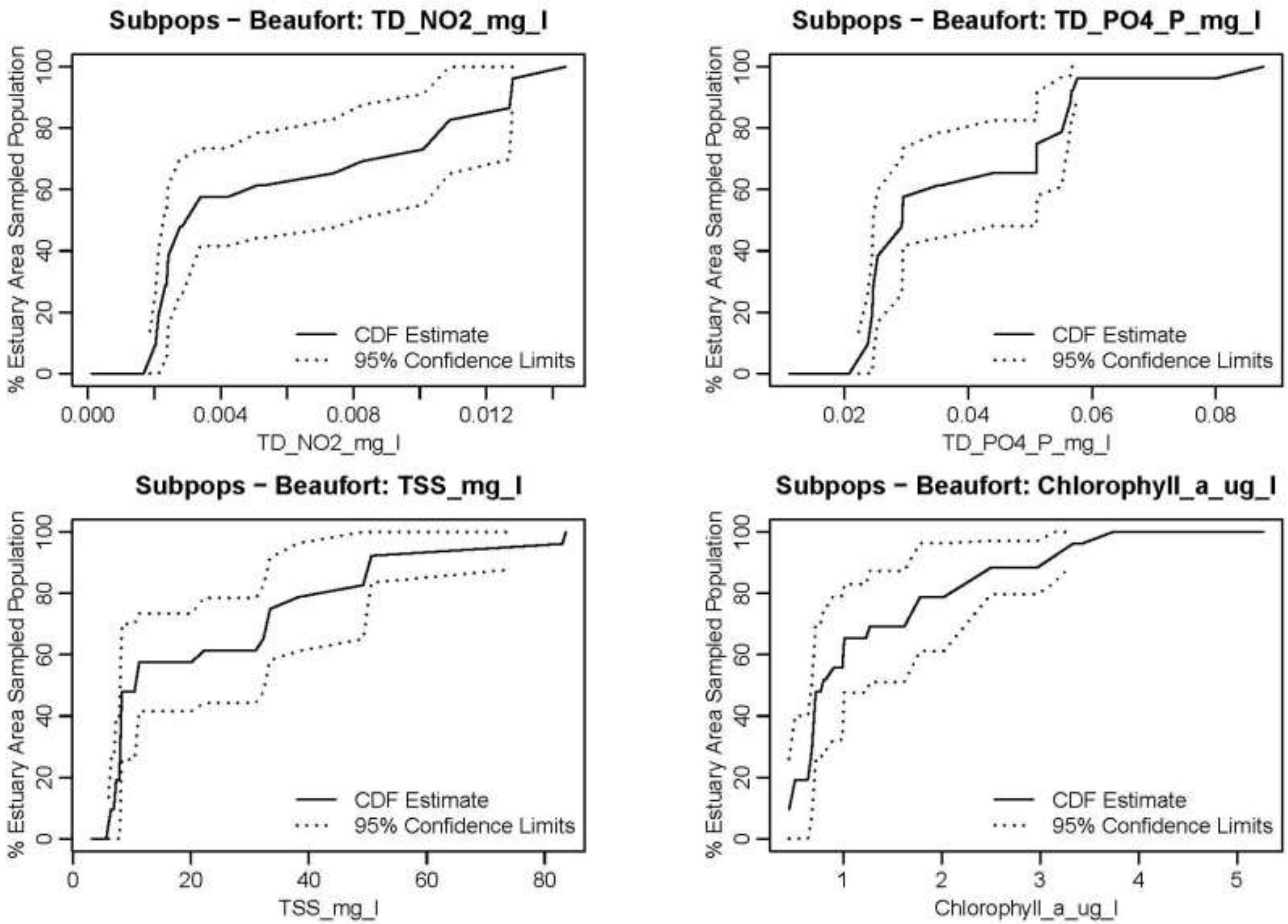


Figure D.8. NPR-A Beaufort stratum ~ 1 meter depth NO_2, PO_4 as P mg/L, TSS mg/L, and chlorophyll *a* ug/L.

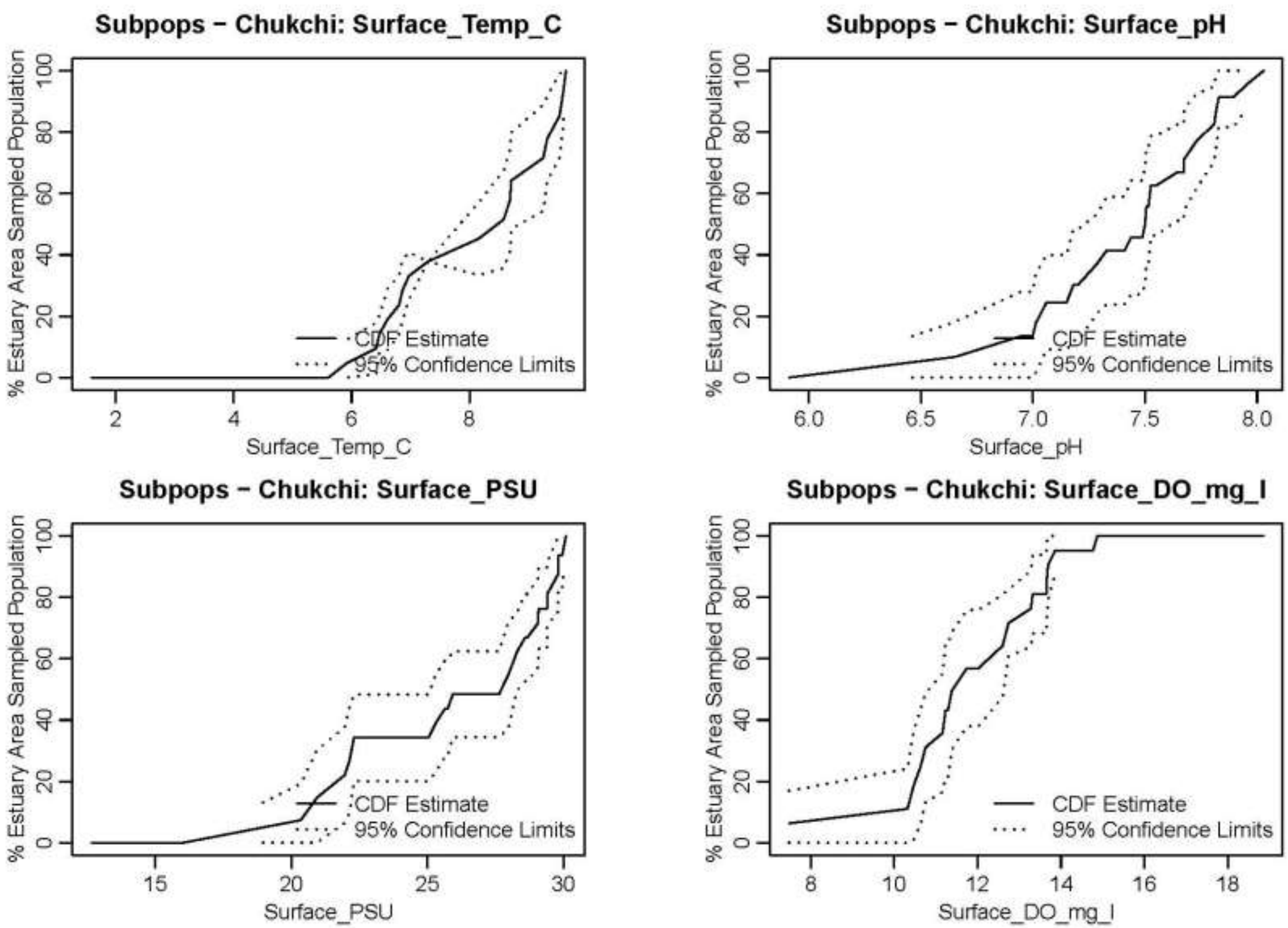


Figure D.9. NPR-A Chukchi stratum surface temperature ^{o}C, pH, PSU, and DO mg/L.

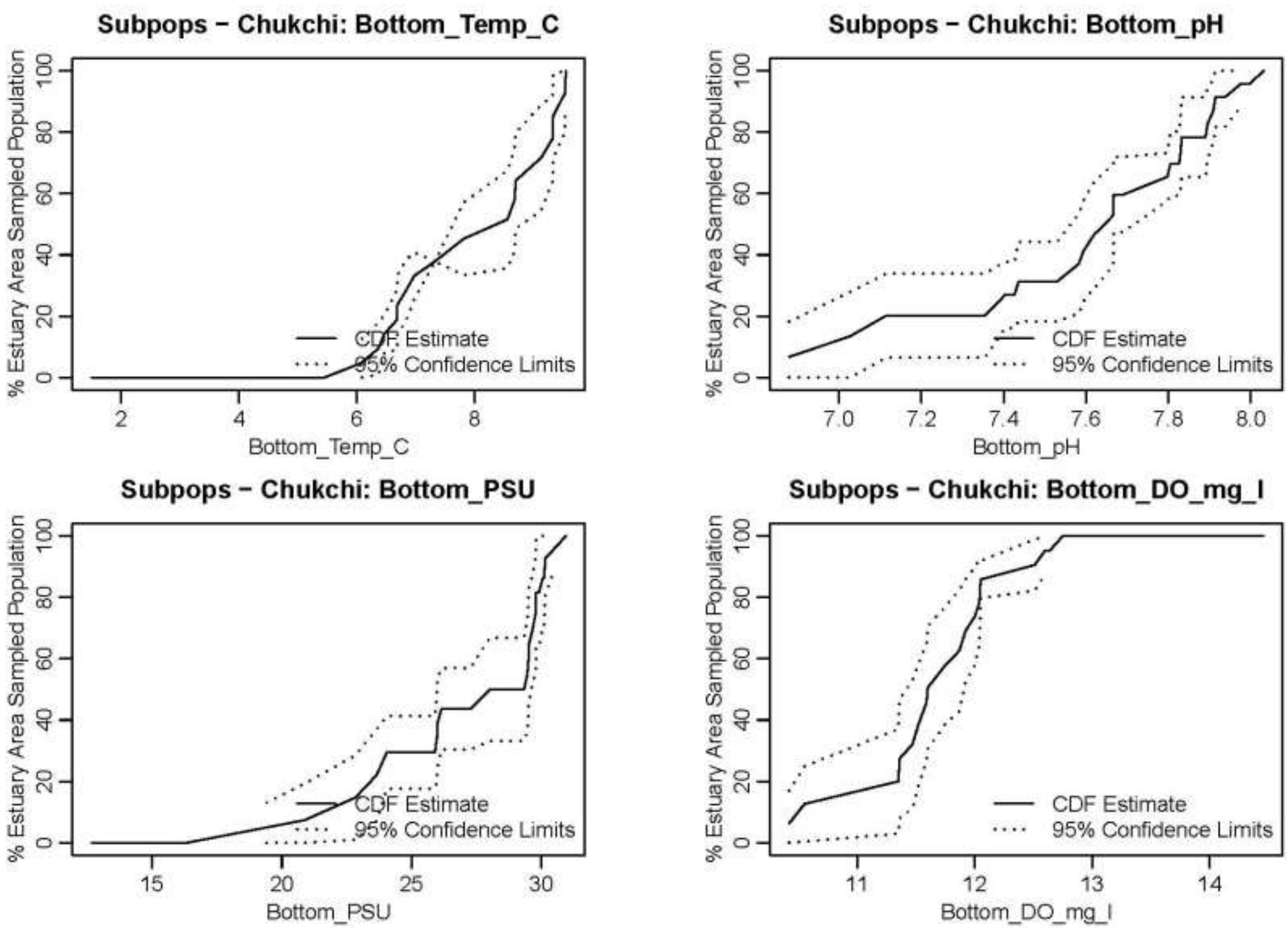


Figure D.10. NPR-A Chukchi stratum bottom temperature °C, pH, PSU, and DO mg/L.

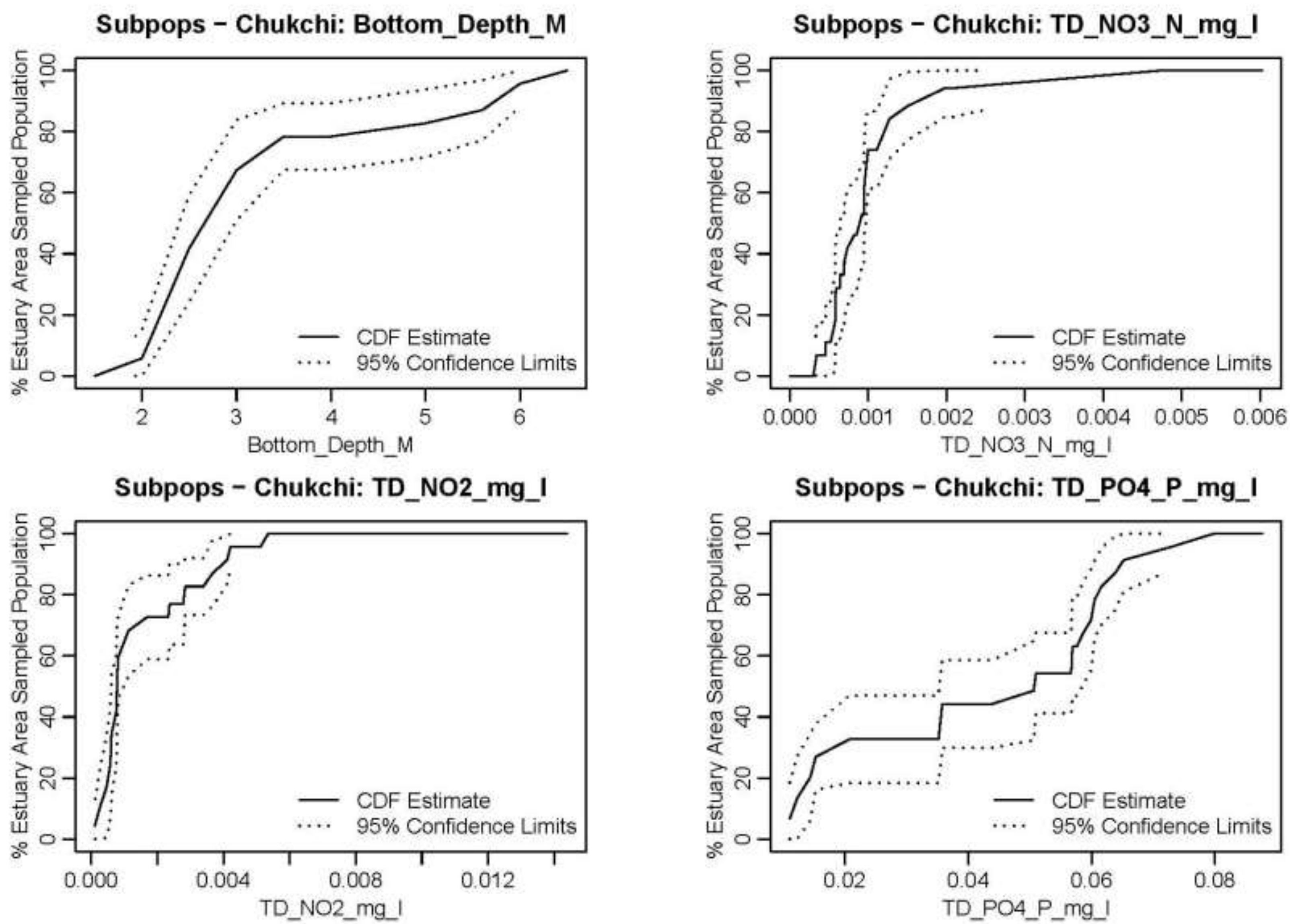


Figure D.11. NPR-A Chukchi stratum station bottom depth M, and ~ 1 meter depth TD NO_3 as N, NO_2, and PO_4 as P mg/L.

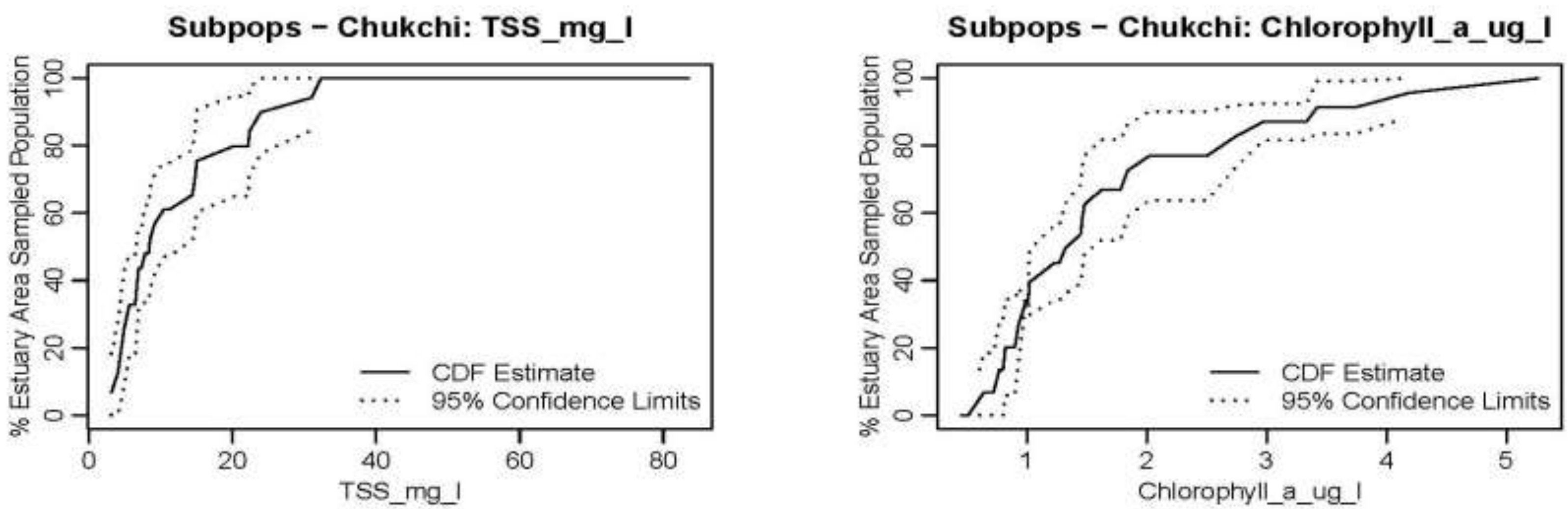


Figure D.12. NPR-A Chukchi stratum TSS mg/L and chlorophyll a ug/L.

Appendix E: Sediment Physical, Trace Metal and PAH Data

Table E.1. Sediment physical properties.

Variable	Strata	# Obs.	Minimum	Maximum	Median	Mean	Geo-Mean	SD	SEM	MAD/0.675	Skewness	CV
Gravel %	NPR-A	32	0.00	6.22	0.01	0.31	0.00	1.11	0.20	0.01	5.19	3.61
	Beaufort	13	0.00	6.22	0.00	0.61	0.00	1.73	0.48	0.00	3.32	2.84
	Chukchi	19	0.00	0.56	0.03	0.10	0.00	0.14	0.03	0.04	2.14	1.41
Sand %	NPR-A	32	1.49	98.67	12.35	24.06	13.77	28.08	4.97	11.46	1.84	1.17
	Beaufort	13	3.52	95.90	11.72	25.31	15.58	27.40	7.60	10.78	1.70	1.08
	Chukchi	19	1.49	98.67	14.58	23.21	12.66	29.26	6.71	12.23	2.08	1.26
Mud %	NPR-A	32	1.24	98.48	87.66	75.74	57.38	28.36	5.01	10.51	-1.81	0.37
	Beaufort	13	3.81	96.48	88.28	74.08	61.32	27.97	7.76	10.78	-1.60	0.38
	Chukchi	19	1.24	98.48	85.42	76.88	54.83	29.32	6.73	11.96	-2.09	0.38
TOC %	NPR-A	32	0.15	4.94	2.55	2.33	1.82	1.19	0.21	0.89	0.00	0.51
	Beaufort	13	0.22	4.94	2.44	2.30	1.84	1.23	0.34	0.96	0.26	0.54
	Chukchi	19	0.15	4.67	2.60	2.35	1.81	1.20	0.28	0.72	-0.17	0.51
$\delta^{13}C$ ‰	NPR-A	32	-27.50	-20.95	-25.92	-25.64	N/A	1.34	0.24	0.82	2.04	-0.05
	Beaufort	13	-27.50	-25.90	-26.56	-26.53	N/A	0.43	0.12	0.34	-0.60	-0.02
	Chukchi	19	-26.46	-20.95	-25.44	-25.03	N/A	1.42	0.33	0.91	1.92	-0.06
$\delta^{15}N$ ‰	NPR-A	32	0.33	8.96	2.60	3.12	2.58	1.94	0.34	1.42	1.39	0.62
	Beaufort	13	0.33	2.78	1.88	1.79	1.62	0.66	0.18	0.46	-0.54	0.37
	Chukchi	19	0.84	8.96	4.13	4.03	3.55	2.02	0.46	1.75	1.02	0.50

Coefficient of variation (CV): A dimensionless quantity used to measure the spread of data relative to the size of the numbers. It is also known as the relative standard deviation (RSD).

Median absolute deviation (MAD): A robust measure of spread in datasets that is relative resistant to effects if outliers and non-normal distribution compared to other measures of spread such as variance or standard deviation. MAD/0.675 is approximately equal to the standard deviation for normally distributed data.

Standard deviation (*sd*, sd, SD): A measure of variation (or spread) from an average value of the sample data values.

Standard error (SE): A measure of an estimate's variability (or precision). The greater the standard error in relation to the size of the estimate, the less reliable is the estimate. Standard errors are needed to construct confidence intervals for the parameters of interests such as the population mean and population percentiles.

Table E.2. Sediment trace metals (µg/g dw).

Variable	Strata	# Obs	Minimum	Maximum	Median	Mean	Geo-Mean	SD	SEM	MAD/0.675	Skewness	CV
As	NPR-A	32	7.70	34.80	16.45	17.42	16.42	6.17	1.09	4.52	0.86	0.35
	Beaufort	13	8.29	21.10	15.30	15.15	14.62	4.00	1.11	4.60	-0.25	0.26
	Chukchi	19	7.70	34.80	18.80	18.98	17.77	6.97	1.60	7.12	0.61	0.37
Cd	NPR-A	32	0.031	0.187	0.120	0.116	0.108	0.039	0.007	0.040	-0.421	0.337
	Beaufort	13	0.060	0.187	0.131	0.131	0.124	0.039	0.011	0.030	-0.566	0.300
	Chukchi	19	0.031	0.164	0.115	0.106	0.098	0.037	0.008	0.031	-0.596	0.348
Cr	NPR-A	32	13.85	104.00	63.75	62.59	58.06	20.81	3.68	23.35	-0.49	0.33
	Beaufort	13	23.40	104.00	65.00	64.38	60.77	20.71	5.74	23.13	-0.09	0.32
	Chukchi	19	13.85	88.30	62.50	61.37	56.27	21.35	4.90	24.02	-0.75	0.35
Cu	NPR-A	32	4.71	60.60	28.55	28.24	24.36	13.25	2.34	11.34	0.23	0.47
	Beaufort	13	6.65	49.70	35.30	31.80	27.98	13.79	3.82	17.20	-0.41	0.43
	Chukchi	19	4.71	60.60	26.80	25.80	22.16	12.65	2.90	9.93	0.69	0.49
Pb	NPR-A	32	4.38	20.60	14.15	13.63	12.71	4.54	0.80	5.63	-0.45	0.33
	Beaufort	13	6.30	20.60	14.10	13.60	12.89	4.29	1.19	3.86	-0.22	0.32
	Chukchi	19	4.38	19.00	14.20	13.64	12.59	4.82	1.11	5.97	-0.59	0.35
Hg	NPR-A	32	0.003	0.088	0.060	0.055	0.043	0.025	0.004	0.019	-0.776	0.449
	Beaufort	13	0.004	0.087	0.065	0.055	0.045	0.024	0.007	0.014	-0.969	0.444
	Chukchi	19	0.003	0.088	0.057	0.055	0.042	0.025	0.006	0.026	-0.728	0.464
Ni	NPR-A	32	6.61	55.50	33.10	31.31	28.67	10.81	1.91	9.34	-0.54	0.35
	Beaufort	13	10.90	55.50	39.70	34.98	32.54	11.98	3.32	8.15	-0.46	0.34
	Chukchi	19	6.61	39.20	31.30	28.80	26.28	9.44	2.17	6.97	-1.40	0.33
Ag	NPR-A	32	0.051	0.168	0.090	0.094	0.089	0.032	0.006	0.036	0.604	0.345
	Beaufort	13	0.052	0.168	0.120	0.110	0.103	0.038	0.011	0.042	-0.089	0.346
	Chukchi	19	0.051	0.125	0.099	0.083	0.080	0.023	0.005	0.024	0.569	0.280
Zn	NPR-A	32	14.70	156.00	101.70	92.16	82.43	34.63	6.12	29.32	-0.68	0.38
	Beaufort	13	26.40	156.00	101.50	94.20	86.04	36.16	10.03	39.81	-0.26	0.38
	Chukchi	19	14.70	126.00	105.00	90.76	80.04	34.48	7.91	22.24	-1.06	0.38

Table E.3. Sediment PAHs (ng/g dw) (Long et al., 1995).

Variable	Strata	# Obs	Minimum	Maximum	Median	Mean	Geo-Mean	SD	SEM	MAD/0.675	Skewness	CV
TPAH_Long	NPR-A	32	5.09	634.20	330.70	322.80	214.90	184.90	32.68	210.80	-0.20	0.57
	Beaufort	13	7.36	450.90	301.10	245.30	175.00	135.90	37.69	106.20	-0.48	0.55
	Chukchi	19	5.09	634.20	445.90	375.90	247.40	198.10	45.44	167.70	-0.65	0.53
LMWTPAH_Long	NPR-A	32	2.79	517.10	235.30	215.40	140.90	127.00	22.46	108.30	0.05	0.59
	Beaufort	13	4.37	332.70	219.60	178.00	124.40	100.20	27.78	81.39	-0.44	0.56
	Chukchi	19	2.79	517.10	278.80	241.00	153.50	139.30	31.96	114.10	-0.13	0.58
HMWTPAH_Long	NPR-A	32	2.31	290.70	88.20	107.40	69.95	75.51	13.35	47.71	0.77	0.70
	Beaufort	13	2.98	118.10	81.48	67.26	50.13	35.80	9.93	24.78	-0.58	0.53
	Chukchi	19	2.31	290.70	117.10	134.80	87.87	83.71	19.21	85.61	0.19	0.62
Ace	NPR-A	32	0.05	8.98	2.15	3.25	1.88	2.85	0.50	1.62	0.91	0.88
	Beaufort	13	0.05	2.75	1.76	1.54	1.11	0.86	0.24	1.04	-0.43	0.56
	Chukchi	19	0.08	8.98	3.38	4.43	2.69	3.15	0.72	4.83	0.13	0.71
Acl	NPR-A	30	0.02	1.66	1.10	1.02	0.82	0.46	0.08	0.48	-0.62	0.45
	Beaufort	13	0.02	1.37	0.99	0.81	0.56	0.44	0.12	0.26	-0.70	0.54
	Chukchi	17	0.40	1.66	1.38	1.19	1.10	0.41	0.10	0.28	-0.84	0.35
An	NPR-A	31	0.03	3.15	1.39	1.41	1.09	0.77	0.14	0.43	0.52	0.54
	Beaufort	13	0.10	1.97	1.31	1.14	0.91	0.57	0.16	0.46	-0.62	0.50
	Chukchi	18	0.03	3.15	1.40	1.61	1.24	0.85	0.20	0.63	0.43	0.53
BaA	NPR-A	32	0.28	34.09	6.80	10.09	6.18	9.02	1.59	3.03	1.38	0.89
	Beaufort	13	0.38	8.57	5.87	4.96	3.93	2.50	0.69	1.69	-0.56	0.50
	Chukchi	19	0.28	34.09	8.82	13.60	8.42	10.19	2.34	9.53	0.69	0.75
BaP	NPR-A	32	0.16	22.88	5.66	7.55	4.70	6.19	1.09	3.48	1.13	0.82
	Beaufort	13	0.16	7.29	5.61	4.49	3.30	2.34	0.65	1.50	-0.78	0.52
	Chukchi	19	0.21	22.88	5.88	9.64	5.98	7.14	1.64	8.30	0.50	0.74
C0	NPR-A	32	0.82	74.63	37.99	37.30	25.69	20.78	3.67	21.55	-0.17	0.56
	Beaufort	13	1.11	53.61	34.98	28.88	21.08	15.92	4.42	11.79	-0.45	0.55
	Chukchi	19	0.82	74.63	49.18	43.06	29.41	22.10	5.07	26.62	-0.56	0.51
DA	NPR-A	32	0.10	9.70	2.37	3.10	2.00	2.50	0.44	1.51	1.13	0.81
	Beaufort	13	0.10	3.33	1.98	1.78	1.37	0.93	0.26	0.79	-0.33	0.53
	Chukchi	19	0.10	9.70	2.73	4.00	2.58	2.83	0.65	3.60	0.49	0.71
FL	NPR-A	32	0.52	90.65	18.67	27.40	16.31	23.80	4.21	8.42	1.24	0.87
	Beaufort	13	0.62	23.06	16.34	13.57	10.20	7.06	1.96	4.80	-0.65	0.52
	Chukchi	19	0.52	90.65	23.85	36.87	22.48	26.64	6.11	30.46	0.56	0.72
F0	NPR-A	32	0.23	37.59	12.30	15.03	9.33	11.07	1.96	8.51	0.68	0.74
	Beaufort	13	0.23	16.44	10.14	8.80	6.19	5.00	1.39	4.91	-0.35	0.57
	Chukchi	19	0.27	37.59	15.93	19.29	12.34	12.13	2.78	14.31	0.02	0.63
N0	NPR-A	32	0.40	83.93	29.44	29.12	19.21	18.87	3.34	16.62	0.73	0.65
	Beaufort	13	0.76	51.94	34.24	28.07	19.92	15.49	4.30	11.46	-0.48	0.55
	Chukchi	19	0.40	83.93	28.76	29.84	18.74	21.25	4.88	19.33	0.98	0.71
P0	NPR-A	32	1.31	156.00	79.24	78.96	52.47	46.05	8.14	50.97	-0.14	0.58
	Beaufort	13	1.82	109.80	71.64	58.99	42.12	32.93	9.13	26.96	-0.43	0.56
	Chukchi	19	1.31	156.00	109.50	92.62	60.98	49.43	11.34	40.50	-0.62	0.53
Py	NPR-A	32	0.38	58.74	17.72	21.94	14.04	15.71	2.78	10.00	0.71	0.72
	Beaufort	13	0.61	22.27	16.68	13.58	10.14	7.13	1.98	4.61	-0.70	0.53
	Chukchi	19	0.38	58.74	20.51	27.65	17.54	17.49	4.01	24.55	0.08	0.63
Two_MNA	NPR-A	32	0.73	256.60	87,25	86.74	53.11	59.33	10.49	56.44	0.81	0.68
	Beaufort	13	1.41	148.70	98.13	78.66	53.20	44.99	12.48	36.88	-0.42	0.57
	Chukchi	19	0.73	256.60	86.29	92.28	53.05	68.06	15.61	62.90	0.89	0.74

TPAH_Long – total PAH values
LMWTPAH_Long – Suite of low molecular weight PAHs (3 or fewer aromatic rings).
HMWTPAH_Long – Suite of high molecular weight PAHs (4 or more aromatic rings).

Ace – Acenaphthene; Acl – Acenaphthylene; An – Anthracene; BaA - Benzo(a)anthracene; BaP - Benzo(a)pyrene; C0 – Chrysene: DA - Dibenzo(a,h)anthracene; FL – Fluoranthene; F0 - Fluorene; N0 – Naphthalene; P0 – Phenanthrene; PY – Pyrene; 2-MNA - 2-Methylnaphthalene.]

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the sound use of our land and water resources, protecting our fish, wildlife and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island communities.

The Bureau of Ocean Energy Management

The Bureau of Ocean Energy Management (BOEM) works to manage the exploration and development of the nation's offshore resources in a way that appropriately balances economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development and environmental reviews and studies.